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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This workshop on "Automatic Pattern Recognition" represents the second of a series of intensive academic/ government interactions in the field of advanced electro-optics, as part of the Army sponsored University Research Initiative. By documenting the associated technology status and dialogue it is hoped that this baseline will serve all interested parties towards providing a solution to high priority Army requirements. Responsible for program and program execution are Dr. Nicholas George, University of Rochester (ARO-URI) and Dr. Rudy Buser, NVEOC.

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Nicholas George

22b. TELEPHONE *(Include Area Code)*
(716) 275-2417

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The Center for Night Vision and Electro-Optics

OPTOELECTRONIC WORKSHOPS

II

AUTOMATIC PATTERN RECOGNITION

APRIL 7, 1988

sponsored jointly by

ARO-URI Center for Opto-Electronic Systems Research
The Institute of Optics, University of Rochester

OPTOELECTRONIC WORKSHOP

ON

AUTOMATIC PATTERN RECOGNITION

Organizer: ARO-URI-University of Rochester
and Center for Night Vision and Electro-Optics

1. INTRODUCTION

2. SUMMARY -- INCLUDING FOLLOW-UP

3. VIEWGRAPH PRESENTATIONS

   A. Center for Opto-Electronic Systems Research
      Organizer -- Nicholas George

      Image Science -- Overview
      Nicholas George

      Diffraction Pattern Sampling
      Dennis Venable

      Image Retrieval
      Robert Rolleston

   B. Center for Night Vision and Electro-Optics
      Organizer -- Mark Norton

4. LIST OF REFERENCES

5. LIST OF ATTENDEES

6. DISTRIBUTION

1. INTRODUCTION

This workshop on "Automatic Pattern Recognition" represents the second of a series of intensive academic/ government interactions in the field of advanced electro-optics, as part of the Army sponsored University Research Initiative. By documenting the associated technology status and dialogue it is hoped that this baseline will serve all interested parties towards providing a solution to high priority Army requirements. Responsible for program and program execution are Dr. Nicholas George, University of Rochester (ARO-URI) and Dr. Rudy Buser, NVEOC.

2. SUMMARY -- INCLUDING FOLLOW-UP

University of Rochester: The workshop group consisted of Professor Nicholas George, Dr. Thomas Stone, Dr. Robert Rolleston (graduated this year - 1988) and Dennis Venable, planning to graduate in 1989.

The main points of briefings by George, Rolleston, and Venable are as follows:

a. In pattern recognition that is pixal intensive, there is considerable merit in optical **preprocessing** or a parallel channel of processing that works at high rate coupling in auxiliary data to a more conventional all-digital system. Examples are optical transforms in white light (cosine, sine, Hartley, or Fourier), direct correlation schemes as by Morris at UR, and the neural network models that provide high-speed, parallel computation and are being studied at numerous laboratories.

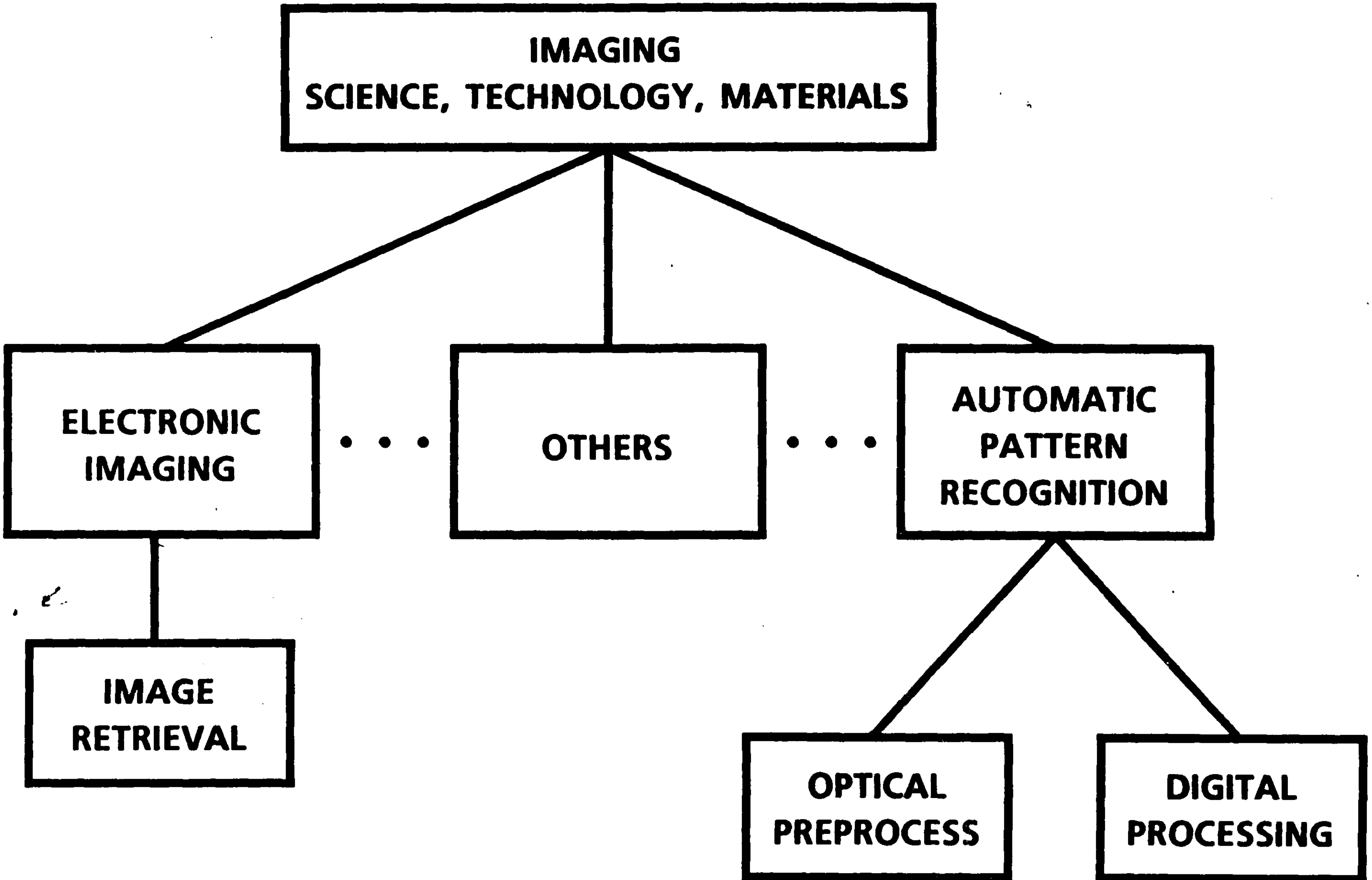
b. Various light valve schemes are getting better and better; and as they do it is worthwhile considering coherent diffraction pattern sampling. Some recent classifications of sortings were described.

c. Image retrieval was described including recent work of Rolleston on Fresnel-zone retrieval.

Imaging of the type simulating current Army objectives in pattern recognition were shown by the Army scientists. There were discussions about UR being able to access these images for test purposes, and we should follow-up on this.

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH

IMAGE SCIENCE -- OVERVIEW



Nicholas George
April, 1988

IMAGE SCIENCE

RESEARCH TRENDS

1950 - 60 - 70 - 80 - 85 - 90 - 95 - 2000

WHITE

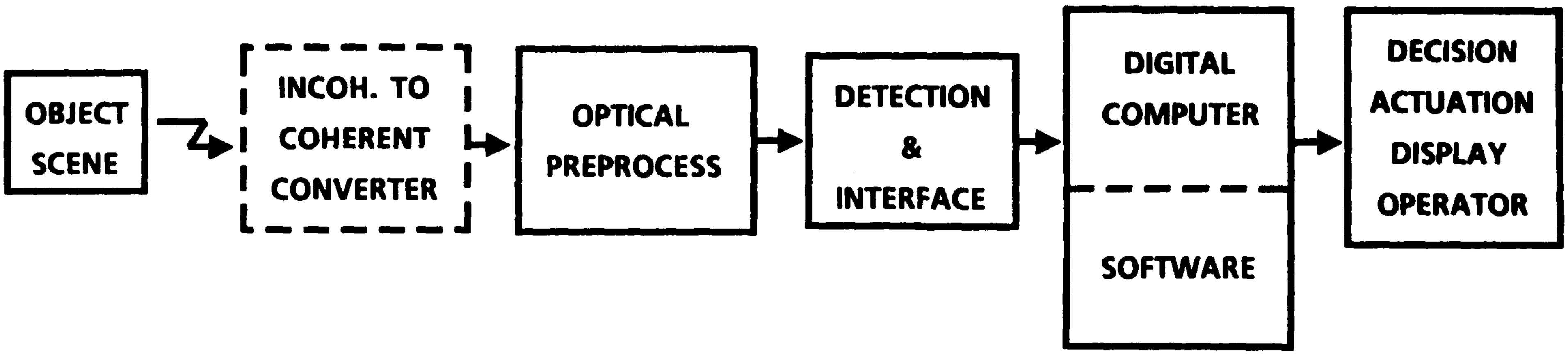
↑ LASER
MONOCHROMATIC

↑ • DEVICES

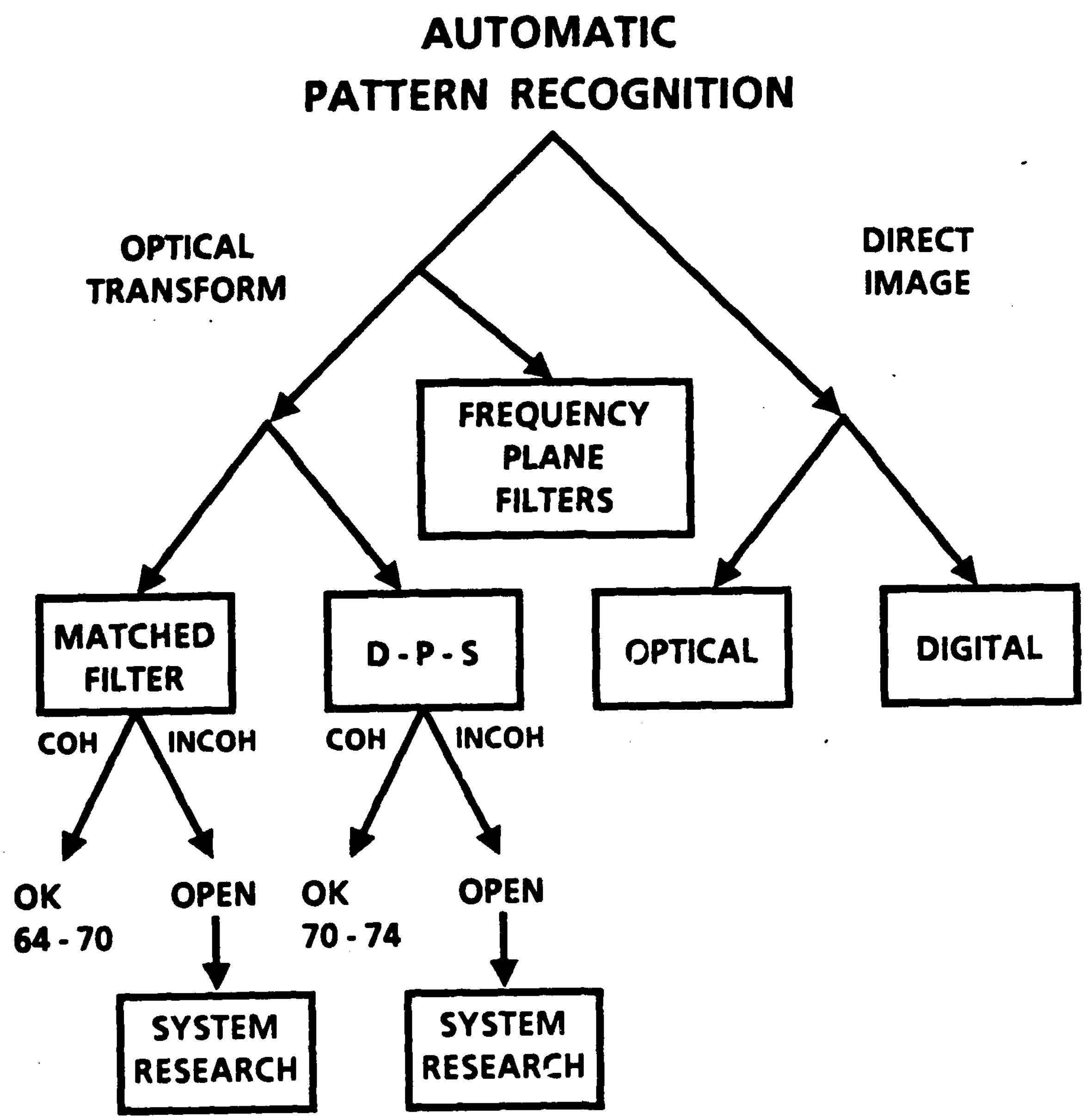
↑ * WHITE LIGHT

- LIGHT VALVES
- NONLINEAR OPTICAL MEDIA
- PHOTOPOLYMERS, NON AgBr

* SYSTEMS - WHITE LIGHT

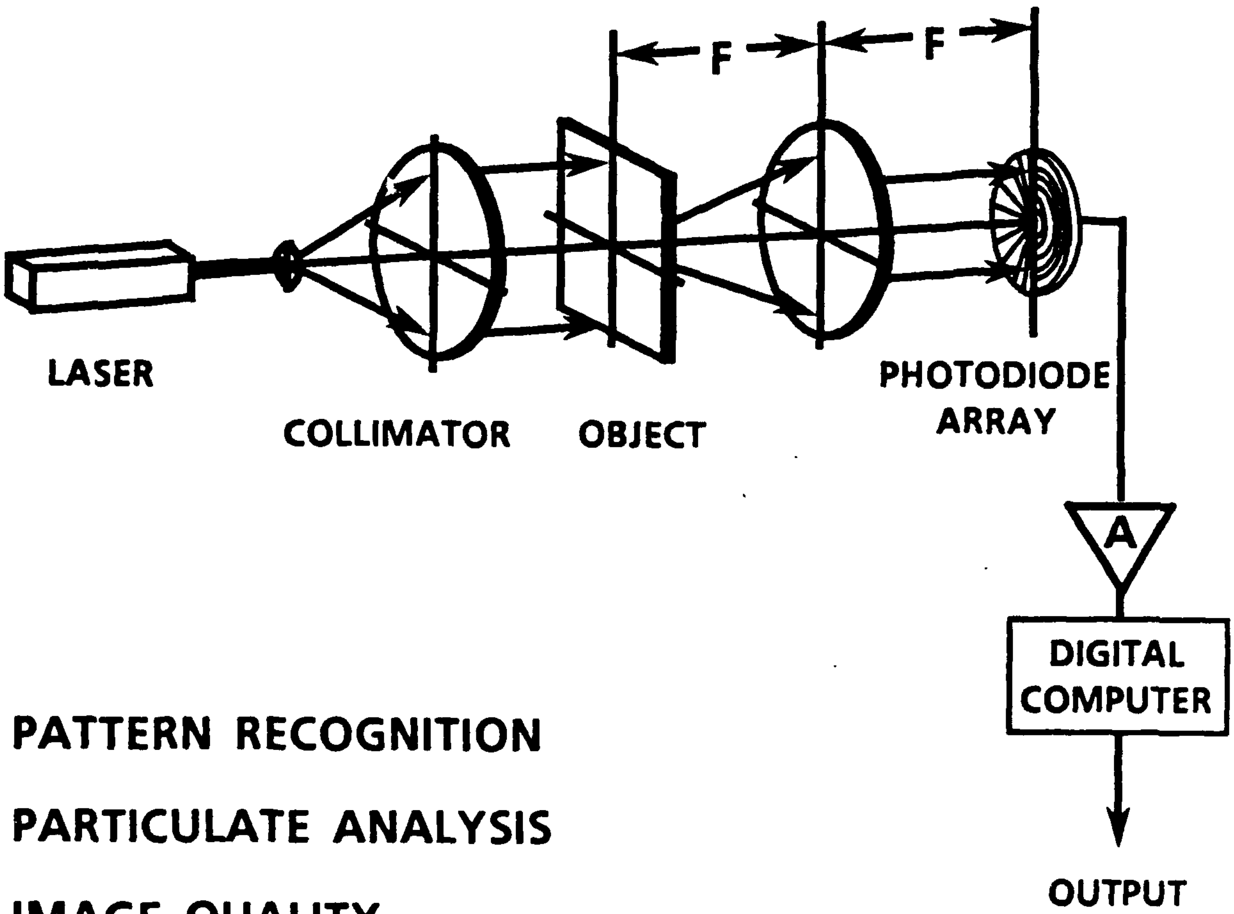


OPTICAL PREPROCESS HYBRID
(GENERIC SYSTEM)


AUTOMATIC
PATTERN RECOGNITION
OPTICAL
TRANSFORM
DIRECT
IMAGE
FREQUENCY
PLANE
FILTERS
MATCHED
FILTER
D - P - S
OPTICAL
DIGITAL
COH
INCOH
COH
INCOH
OK
64 - 70
OPEN
OK
70 - 74
OPEN
SYSTEM
RESEARCH
SYSTEM
RESEARCH

DIFFRACTION PATTERN SAMPLING HYBRID OPTO-ELECTRONIC SYSTEM

- **EFFECTIVE:** LASER & SMOOTH INPUT



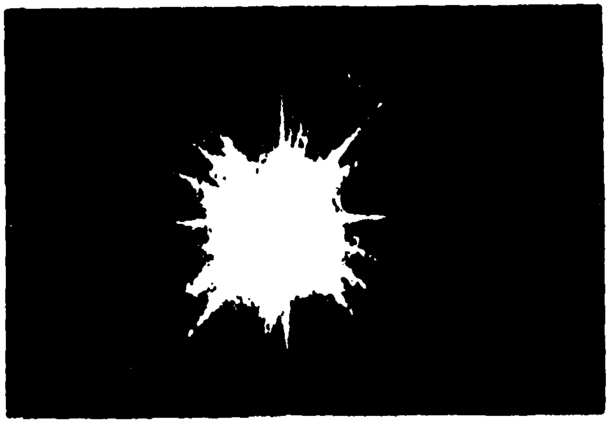
PATTERN RECOGNITION

PARTICULATE ANALYSIS

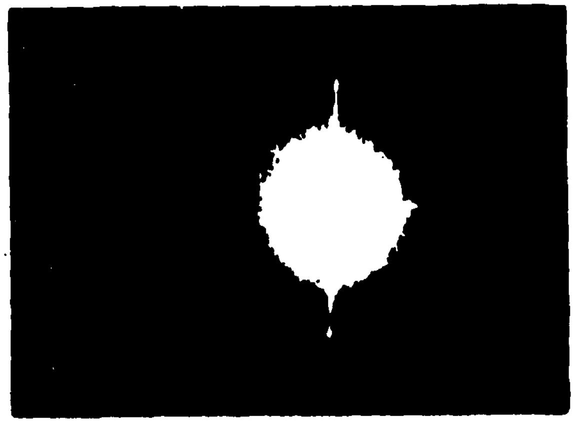
IMAGE QUALITY

NEEDLE SHARPNESS, ...

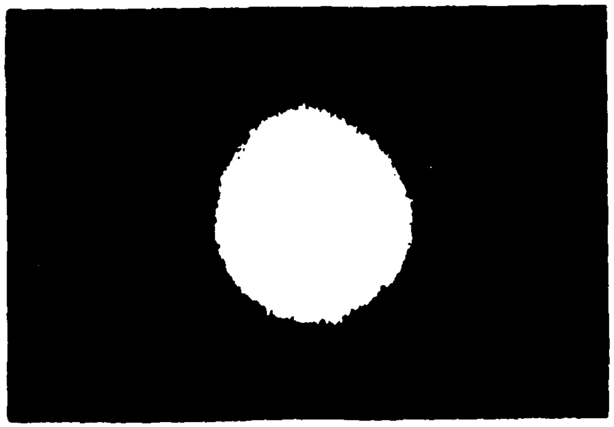
- **INEFFECTIVE:** NORMAL ILLUMINATION AND ROUGH OBJECTS



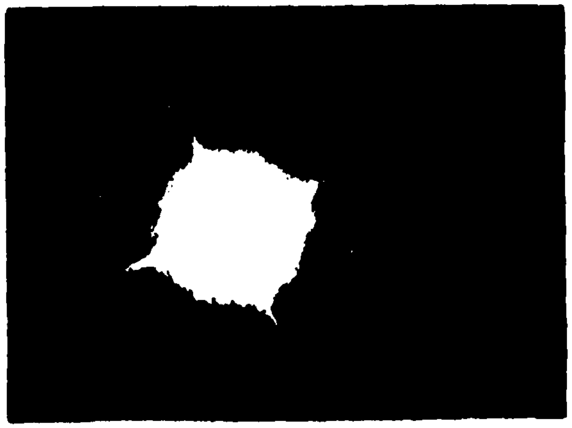
AIRPORT & CITY



PLOWED FIELD



TREES

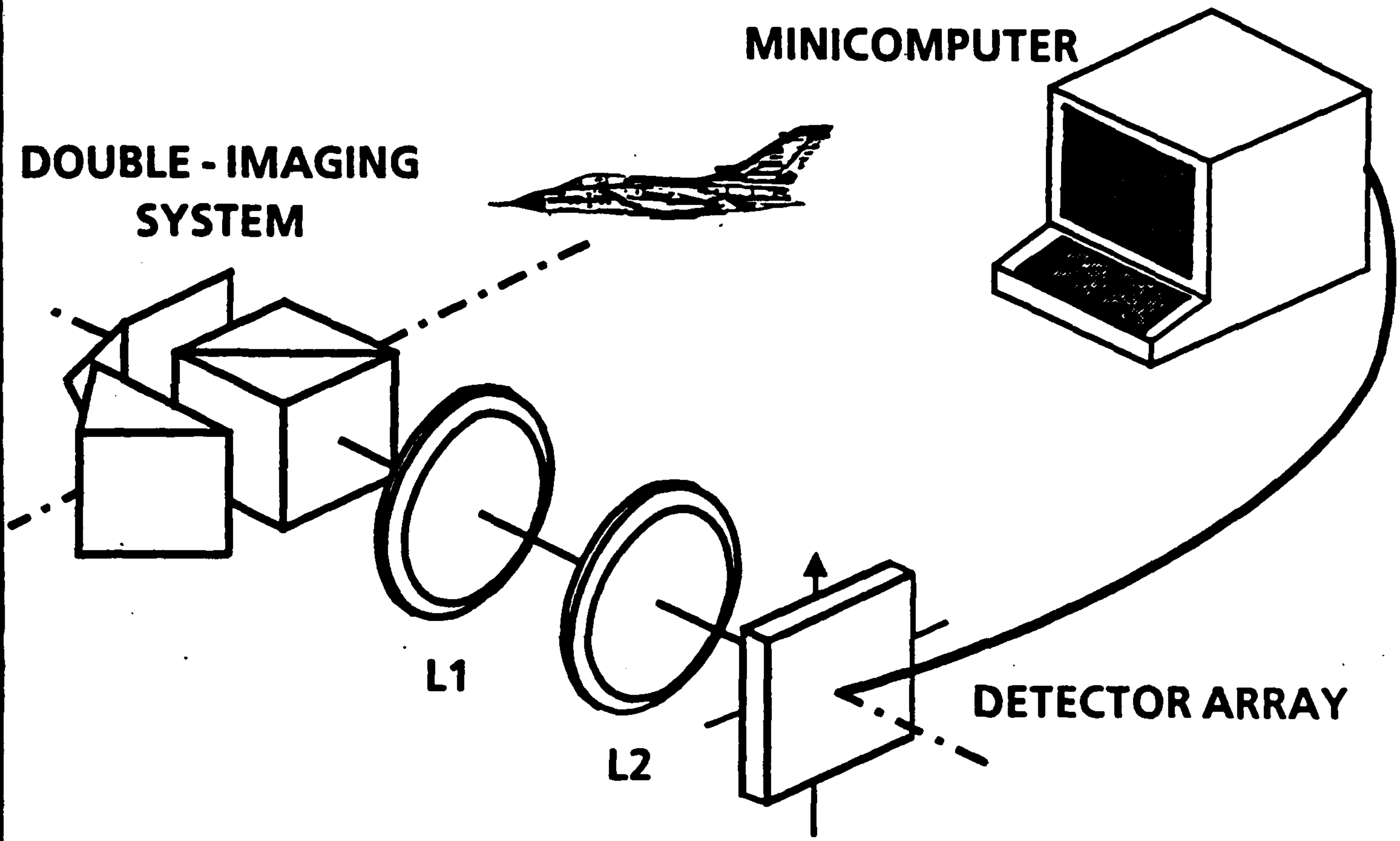


ROAD INTERSECTION

MATCHED FILTERING IN NATURAL ILLUMINATION

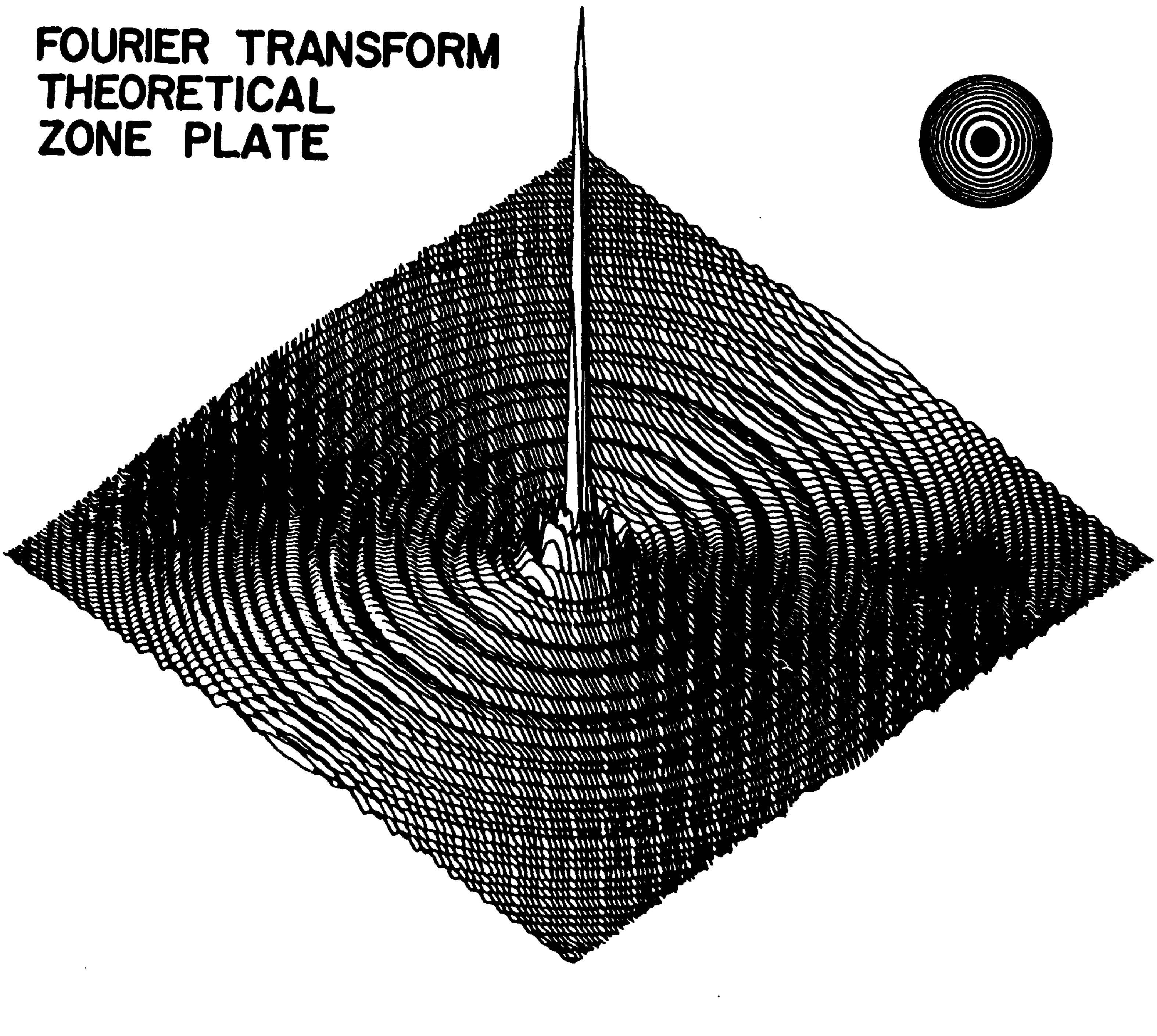
Nicholas George
Shen-ge Wang

- RECENT ACCOMPLISHMENT*

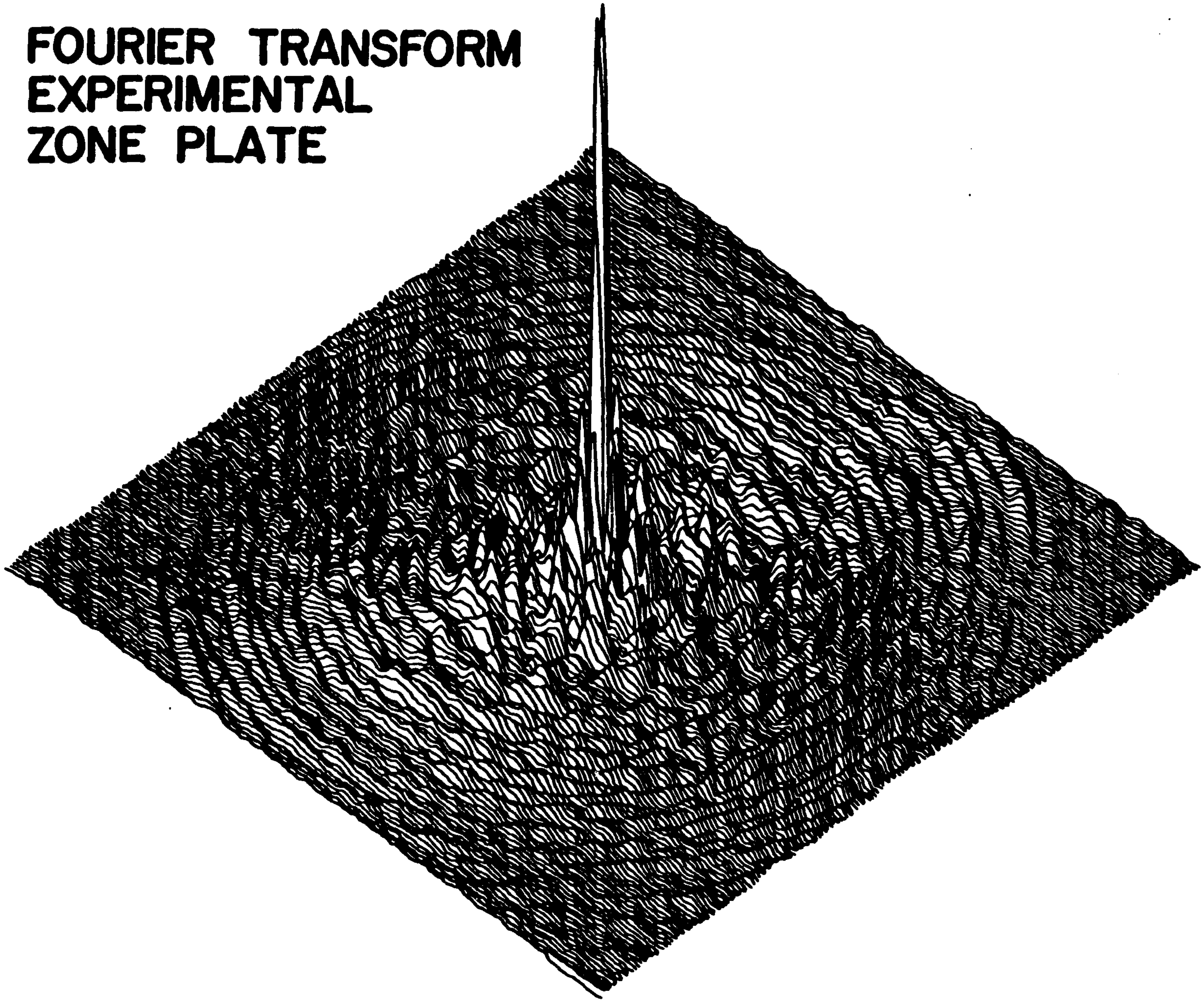


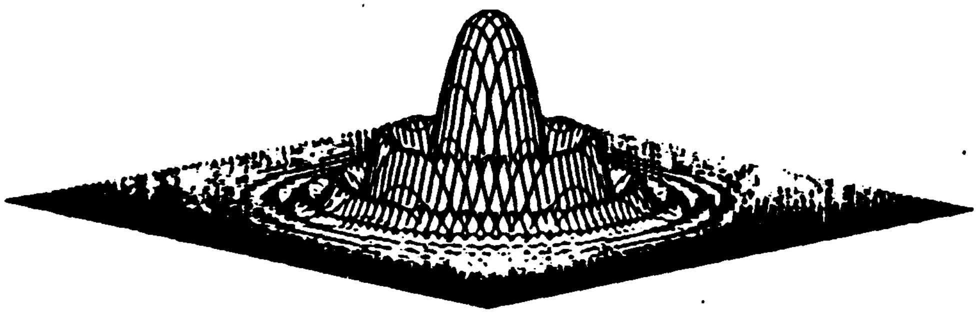
*S. WANG AND N. GEORGE, "CORRELATION AND IMAGE RECONSTRUCTION", JOSA (A) 2, P. 14 (1985).

FOURIER TRANSFORM
THEORETICAL
ZONE PLATE

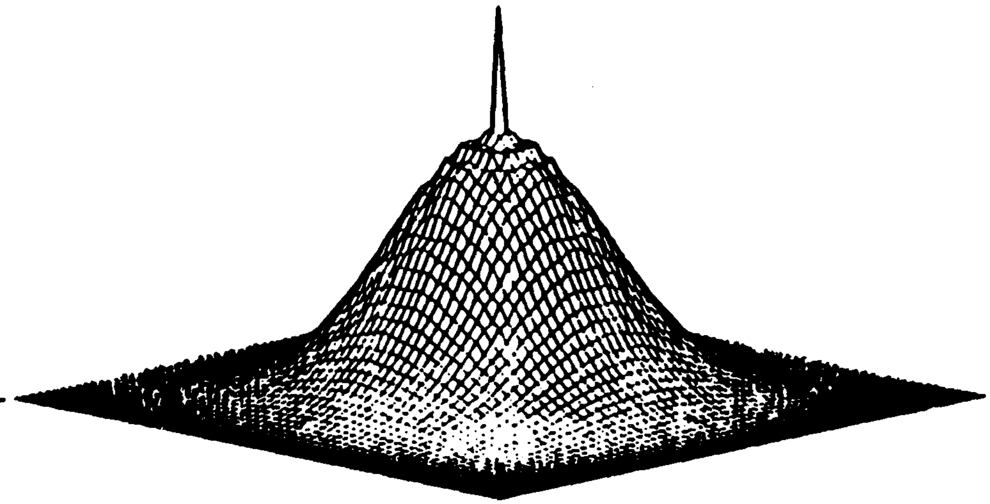


FOURIER TRANSFORM
EXPERIMENTAL
ZONE PLATE





g



g★g   a/b = 3

INTENSITY CHIRP: $[1 + \cos(2\pi/b^2)(x^2 + y^2)] \exp[-(\pi/a^2)(x^2 + y^2)]$

CORRELATION FUCTION: THEORY

CORRELATION FUNCTION

REAL VALUED $f(x, y) = f_e(x, y) + f_o(x, y)$

$$R_{ff}(x, y) = \iint_{-\infty}^{+\infty} f(x' + x, y' + y) f(x', y')\, dx' dy'$$

PROPERTIES:

$$\left| R_{ff}(x, y) \right| \leq R_{ff}(0, 0)$$

$$R_{ff}(x, y) = R_{ff}(-x, -y)$$

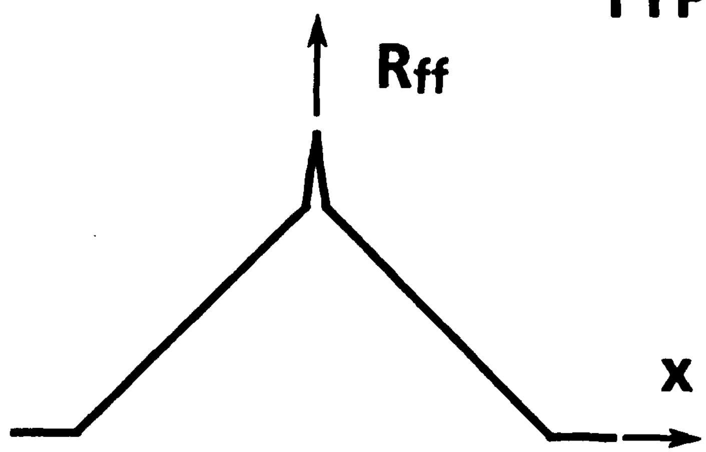
$$R_{ff}(x, y) = R_{ee}(x, y) + R_{oo}(x, y)$$

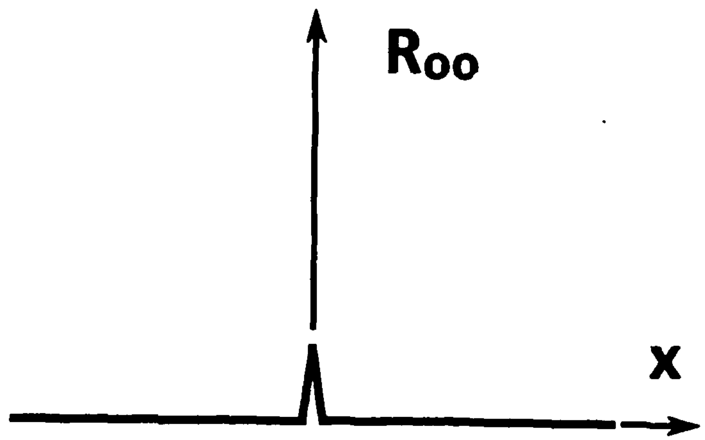
AUTOCORRELATION

REAL-VALUED FUNCTION, $f(x, y)$

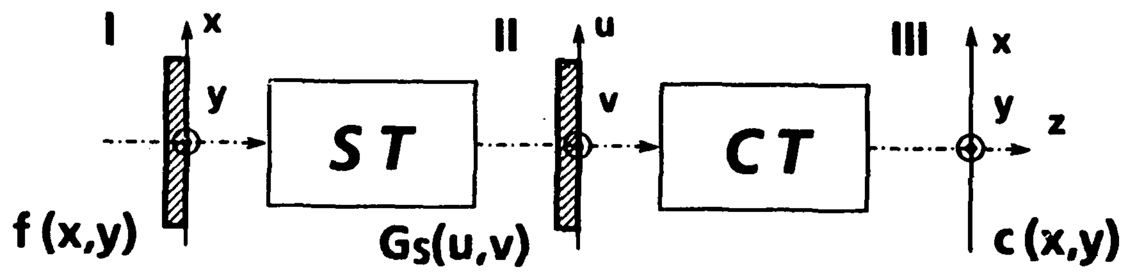
$$R_{\substack{ee\\oo}}(x, y) = \tfrac{1}{2} R_{ff}(x, y) \pm \tfrac{1}{4} f(x, y) * \left[f(x, y) + f(x, y)\big|_{-x,-y} \right]$$

TYPICALLY





SINE - COSINE CASCADE CORRELATOR

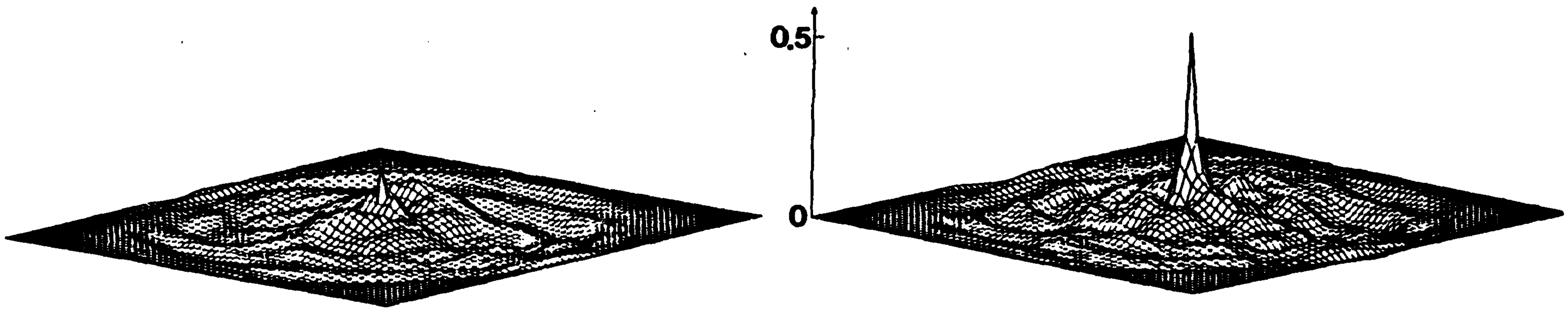


PLANE I TO II:

$$F_S(u, v) = \iint_{-\infty}^{+\infty} f_o(x, y) \mathrm{Sin} 2\pi (ux + vy)\, dxdy$$

OUTPUT III:

$$c(x, y) = \iint_{-\infty}^{+\infty} f_o(x' + x, y' + y) g_o(x', y')\, dx'dy'$$



$10 ★o $1

$1 ★o $1

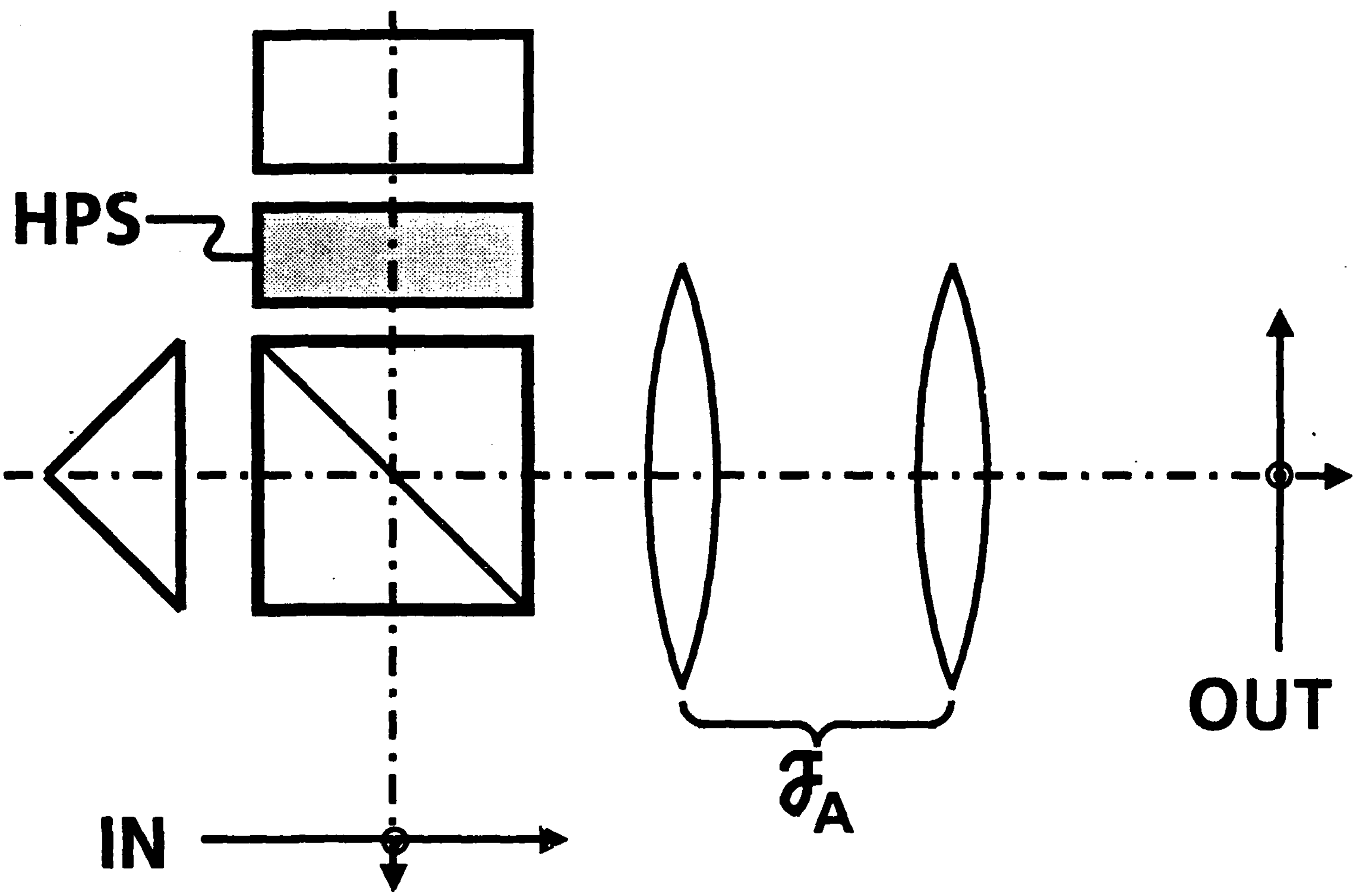
SINE-COSINE CASCADE

COMPUTER SIMULATION (256 x 256 PIXELS)

OPTICAL TRANSFORMS

SPATIAL SINE OR COSINE

COMBINING CONCEPTS

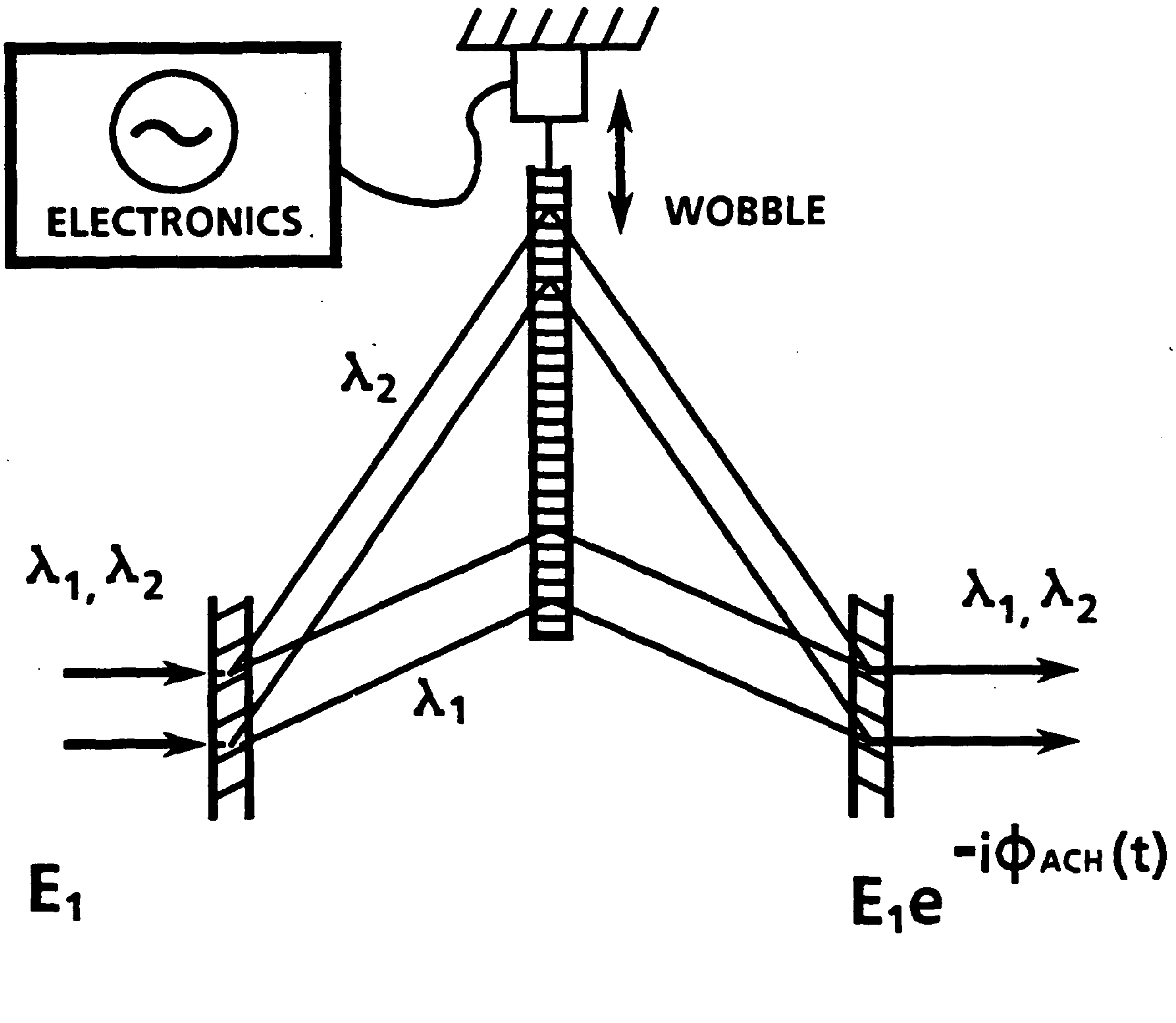


- NOVEL SYSTEM

HOLOGRAPHIC OPTICAL ELEMENTS

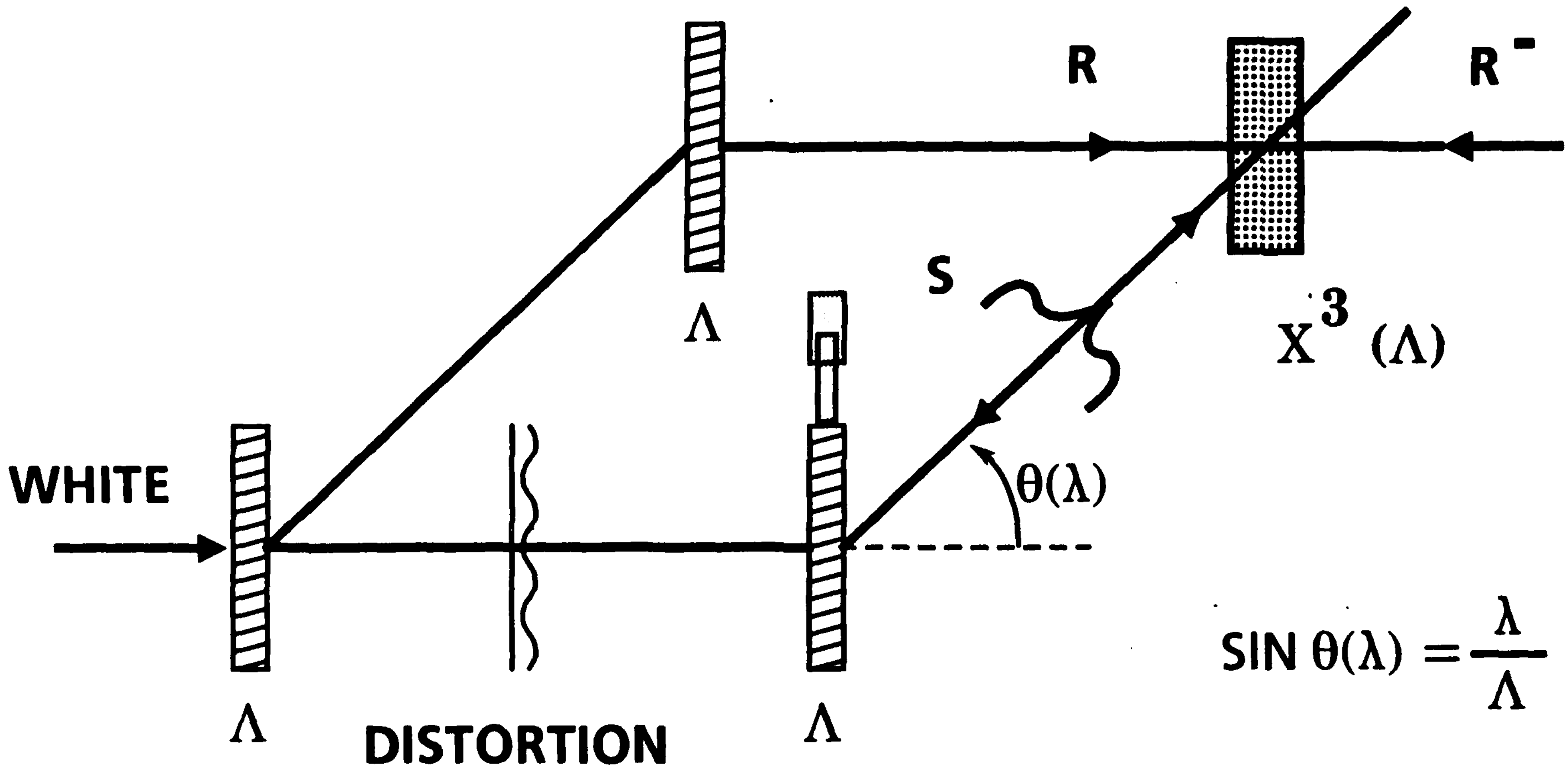
NOVEL CONCEPT (1987)+

BROADBAND ACHROMATIC PHASE SHIFTER



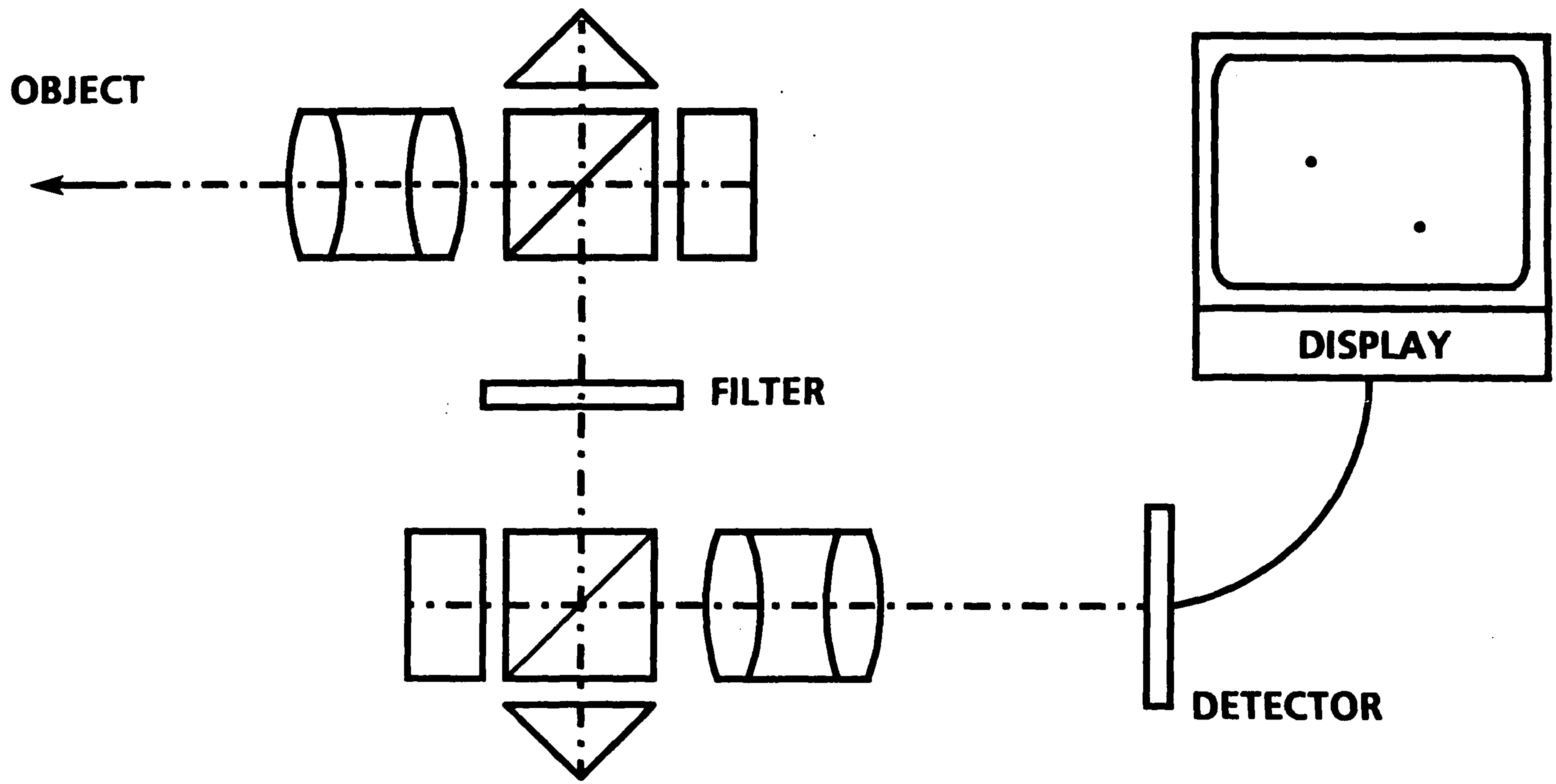
+ Patent Applied For, N. George and T. Stone (1987).

PHASE CONJUGATION
WHITE LIGHT



$$\mathrm{SIN}\,\theta(\lambda) = \frac{\lambda}{\Lambda}$$

N. GEORGE
T. STONE
(UNPUBL)



OPTICAL TRANSFORM & FILTER
(NEXT GENERATION -CONCEPT)

IMAGE SCIENCE
SPATIALLY INCOHERENT ILLUMINATION

MATCHED FILTERING

ACHROMATIC FOURIER TRANSFORM

LIGHT VALVE

DIFFRACTION PATTERN SAMPLING

OPTICAL TRANSFORM -
INTENSITY BASED

LIGHT VALVE

IMAGE RECOVERY

NON-LINEAR CRYSTAL

PHASE CONJUGATION -
INTENSITY BASED

DIGITAL TECHNIQUE

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
DIFFRACTION PATTERN SAMPLING

Automatic Pattern Recognition and Diffraction Pattern Sampling

The Institute of Optics
The University of Rochester

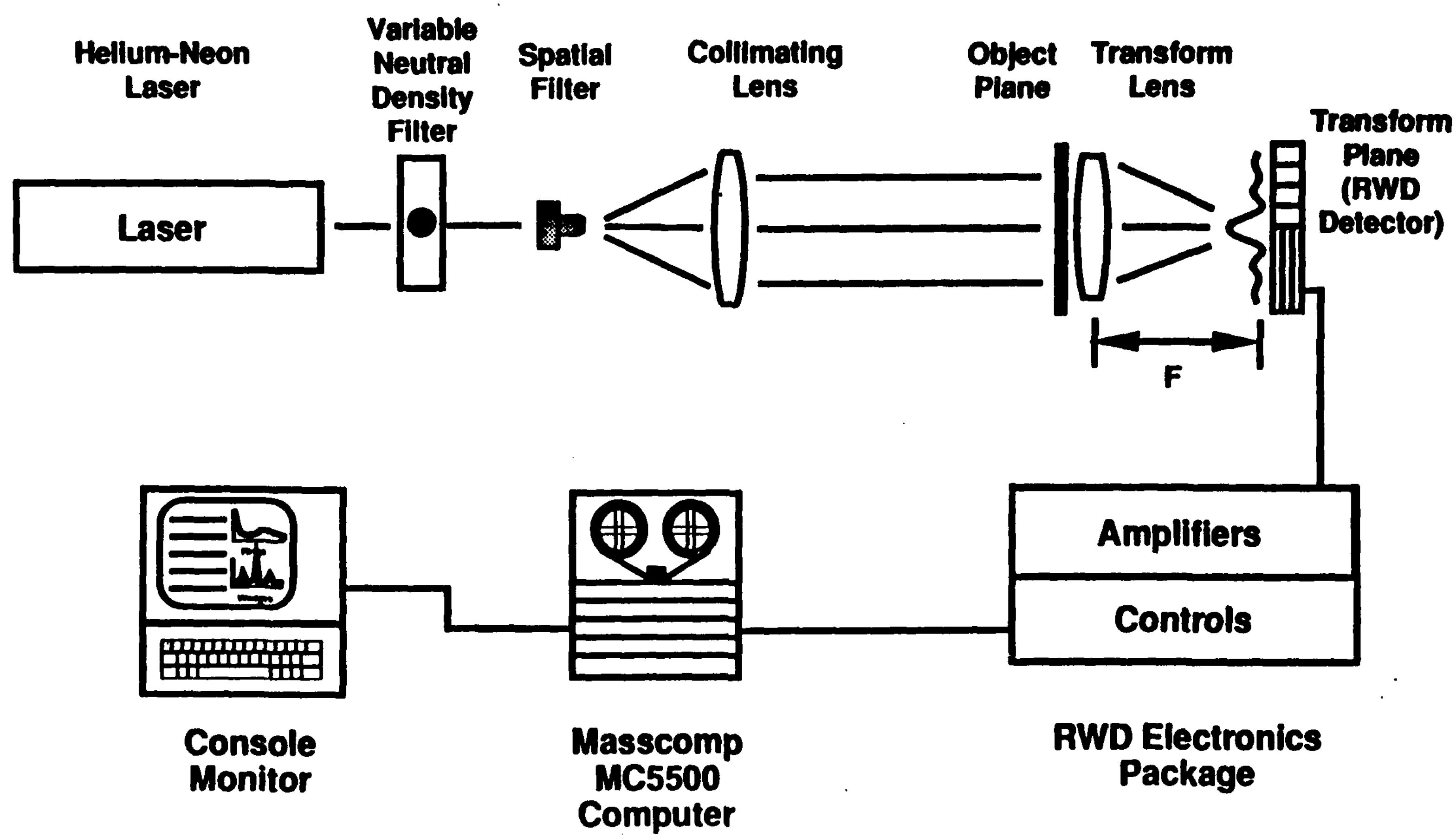
Diffraction Pattern Sampling

Used for: *

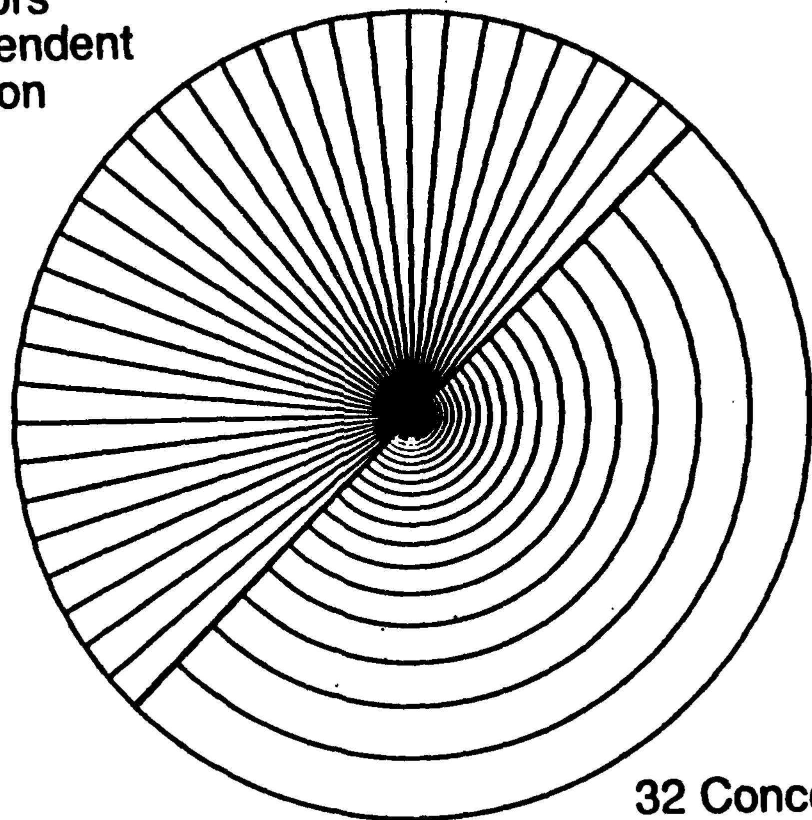
- AERIAL
- CATS/DOGS
- PHOTOMICROGRAPHS
- HYPODERMIC NEEDLES
- HANDWRITING
- PLASTIC FILM
- IMAGE QUALITY
- LENS QUALITY

* George, Nicholas, *Automatic Pattern Recognition*, The Institute of Optics Summer School Notes, 1984

Hybrid-Optic
Diffraction Pattern Sampling System



Ring-Wedge Detector *



* Permission ARC,Inc.
US Patent No. 3,689,772

Analysis of Aerial Photography *

Examples:

- Cloud cover detection
- Detection of anomalies in ocean wave patterns

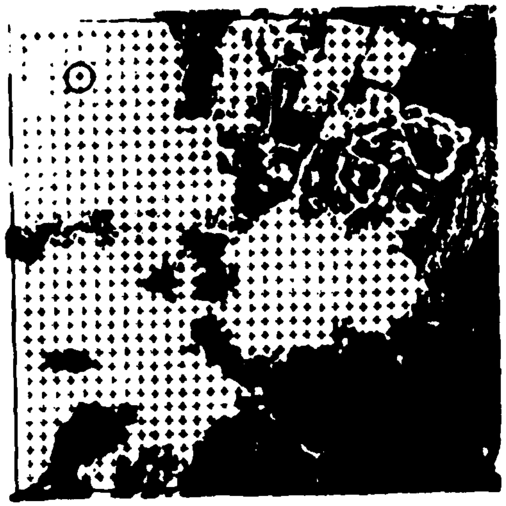


Fig. 5. Sampling grid for cloud test set.

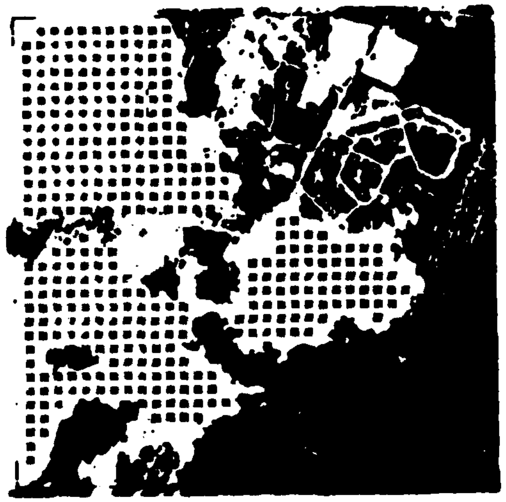


Fig. 6. Results of cloud detection experiment.

Cloud cover detection

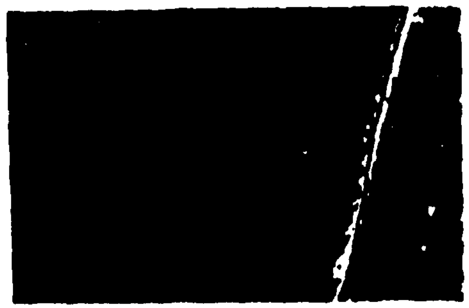


Fig. 7. Sampling apertures for wave patterns.

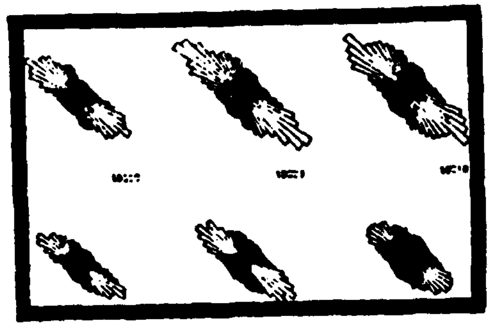


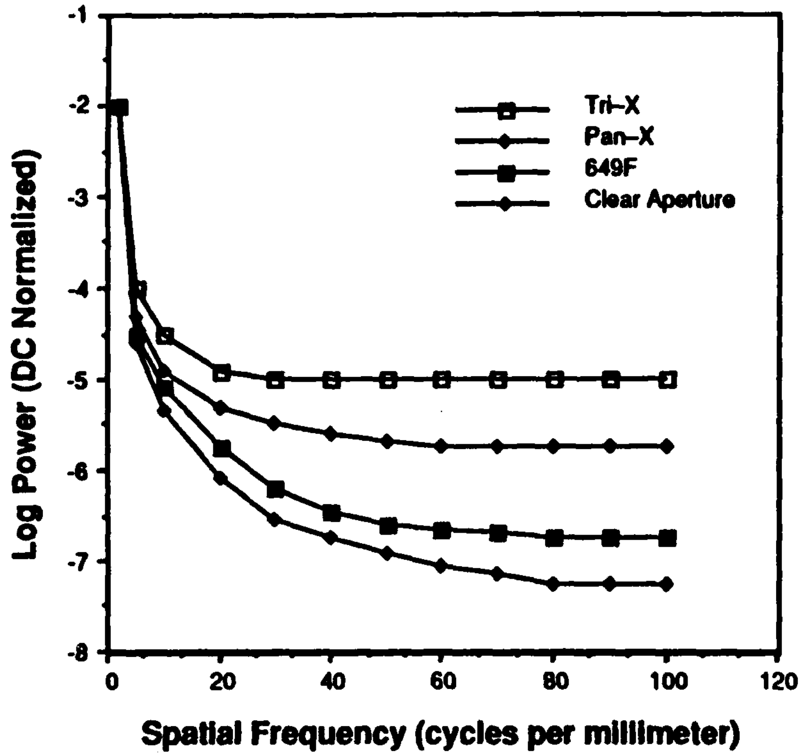
Fig. 8. Rose diagrams of wedge data.

Ocean wave monitoring

* George Lukes, "Rapid Screening of Aerial Photography by OPS Analysis", SPIE vol. 117, 89 (1977).

Film Grain Spectra using Coherent Optical Methods *

* From Armstrong and Thompson, "Comparison of Coherent and Incoherent Optical Spectral Analysis Techniques in Image Evaluation", SPIE vol. 117, pp. 57-66.



Scatterplot indicating tight clustering of film samples. Simple linear descriminants result in very fast recognition (<3 ms).

Notice the easily detectable fingerprint defect.

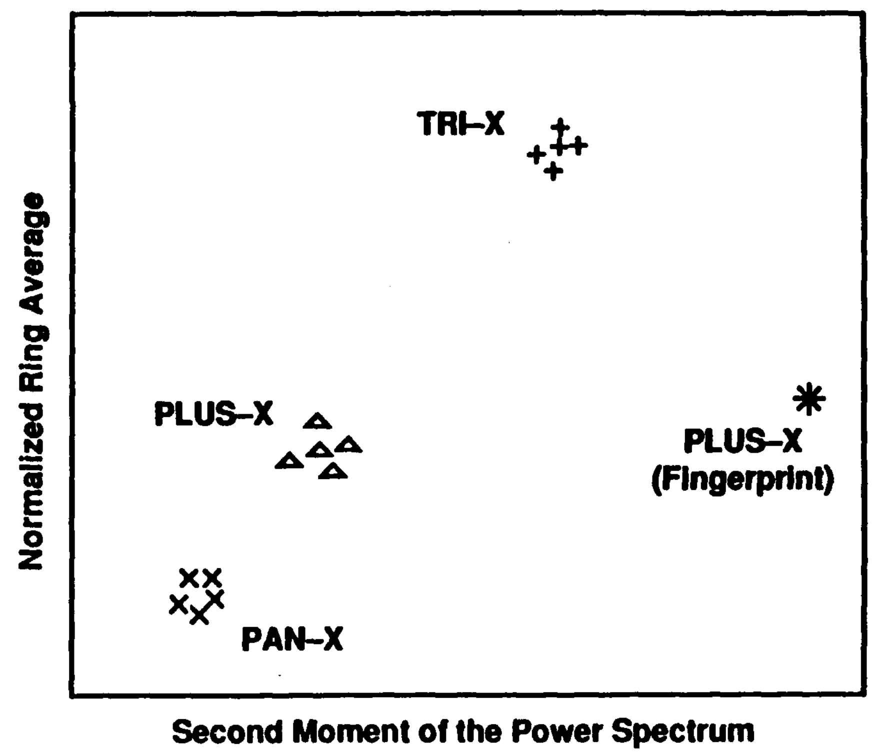
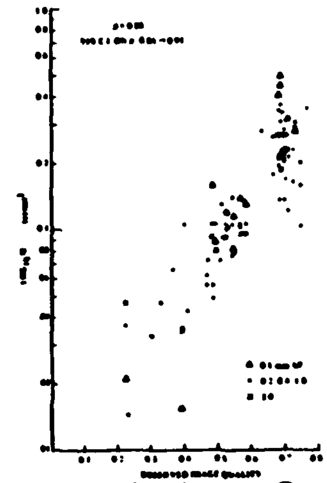


IMAGE QUALITY *

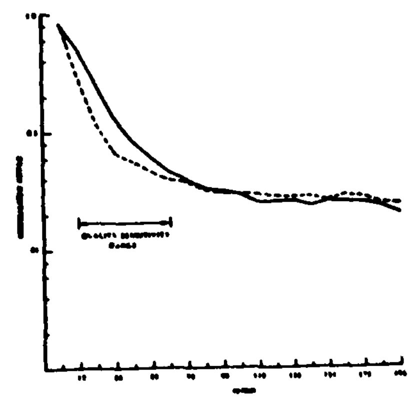
- A low order moment of the coherent power spectra can be useful for image quality evaluation.
- Obtained quantitave results indicating correlation between a low order merit function and subjective image quality measurement.
- There exists a sensitivity range in the optical power spectrum for measuring image quality.
- Aperture effects can be removed from the power spectra for the second moment of the power spectra.

$$M = \frac{\int_0^\infty v^3 P(v)\, dv}{\int_0^\infty v\, P(v)\, dv} - \frac{\int_0^\infty v^3 H(v)\, dv}{\int_0^\infty v\, H(v)\, dv}$$

Second Moment of the Power Spectra



M vrs. Subjective Image Quality



Sensitivty range for Image Quality Measurement

* Norman Nill, "Scene power spectra: the moment as an image quality factor", App. Opt., vol. 15, no. 11, 2846 (1976).

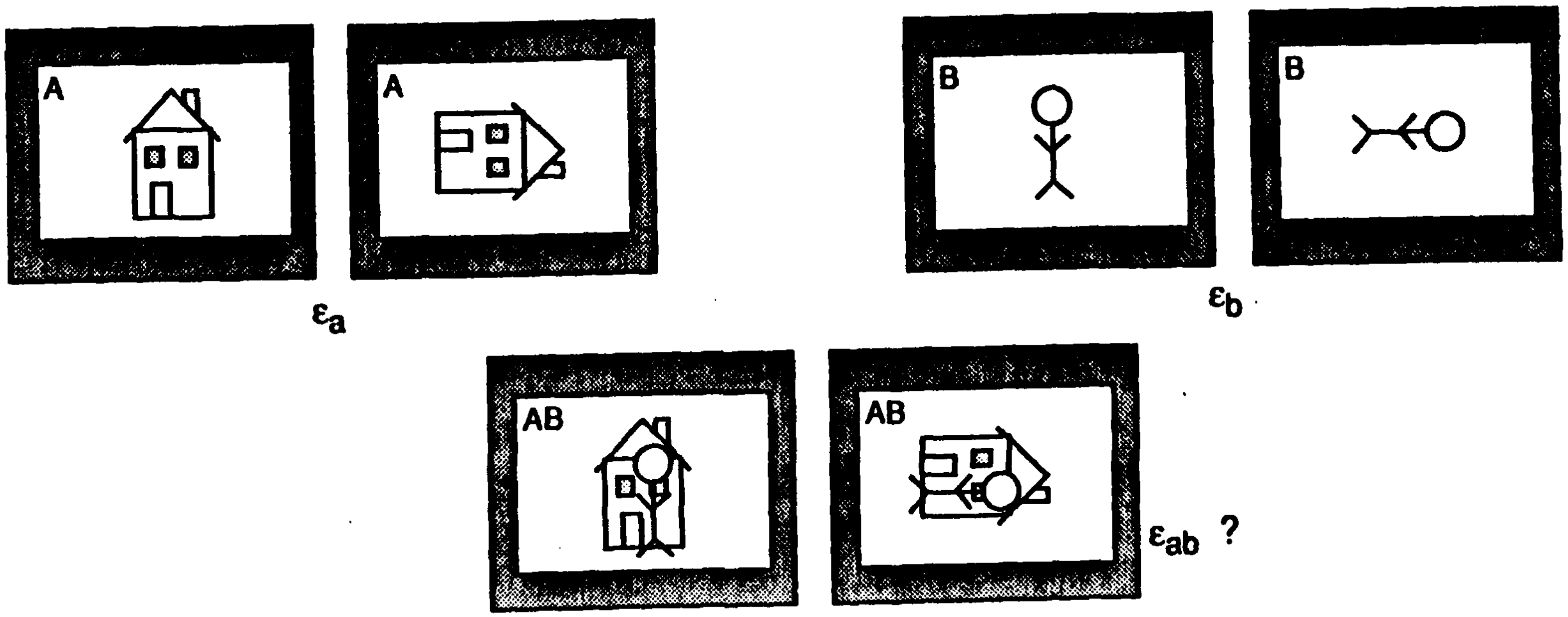
Image Quality

- Predict how defocus in the image affects the optical transform as sampled by the Ring-Wedge Detector
- Can a feature be developed that will optimally determine defocus independent of image content?
- Specific problem:
    - Pick one feature: 2nd Moment of the Power Spectrum
    - Analytically predict how defocus affects this feature
    - Determine defocus from RWD scans of imagery
        - Can aperture effects be removed?
        - Can grain effects be accounted for?
        - Can feature be made image-content independent?
            - Single image - Single image class
            - Single image - Many image classes

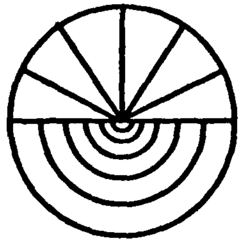
Consider a 2-class sorting problem

- Feature F_a sorts objects A into class 1 and class 2 with a recognition accuracy of ε_a.
- Feature F_b sorts objects B into class 1 and class 2 with a recognition accuracy of ε_b.

Consider an image consisting of both objects A and B. Using only features F_a and F_b, with what recognition accuracy ε_{ab} can the image be sorted into classes 1 or 2 ?



Pooled Wedge Difference Sum Algorithm



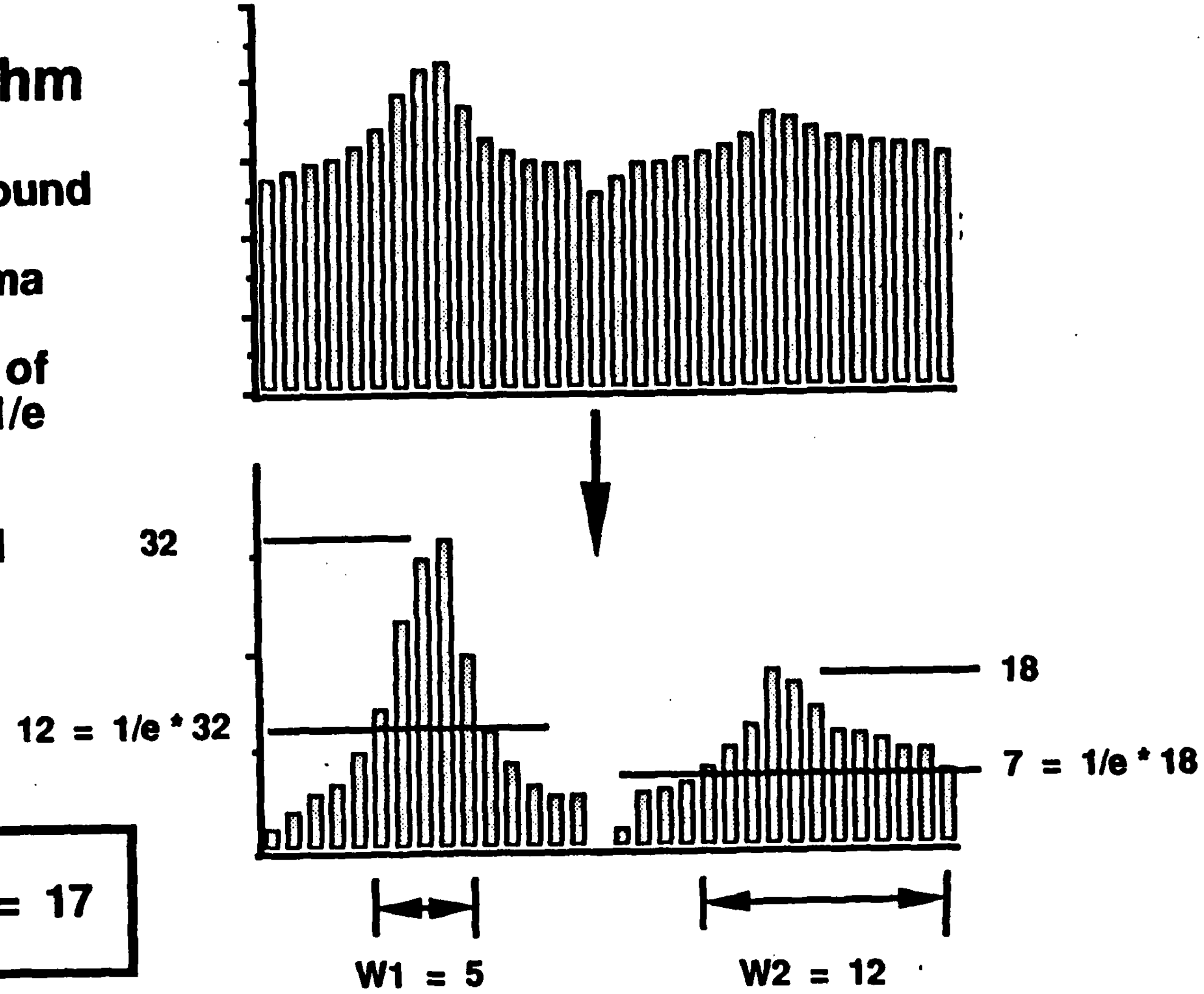
Wedge #	Sample Wedges	Class 1 Pooled Wedges	Differences (Absolute Value)	Class 2 Pooled Wedges	Differences (Absolute Value)
1	129	133	4	126	3
2	237	252	15	133	104
3	153	140	13	139	14
4	149	137	12	140	9
5	156	139	16	230	74
6	129	135	+ 6	135	+ 6
PWDS = $\log(S_1/S_2)$ = -1.574		S_1:	66	S_2:	210

Pooled Wedge Difference Sum Algorithm

The pooled wedge difference sum algorithm is demonstrated above. The PWDS is calculated for a sample against the pooled (average) vectors for classes 1 and 2. Low feature values correspond to a high degree of similarity. In the above example, the sample most nearly matches class 1 as PWDS value of 66 is significantly less than 210.

Spike Width Feature Algorithm

- Subtract background
- Find spike maxima
- Determine width of the spike at the 1/e point
- Add widths of all spikes



$$\boxed{SpW = W1 + W2 = 17}$$

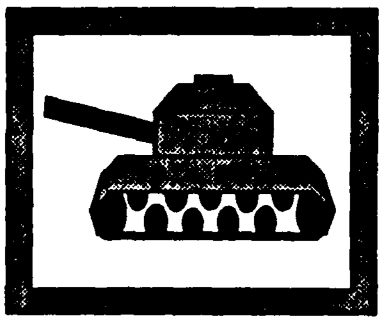
Example of the Spike Width (SpW) feature algorithm.

Orientation Sorting Results:

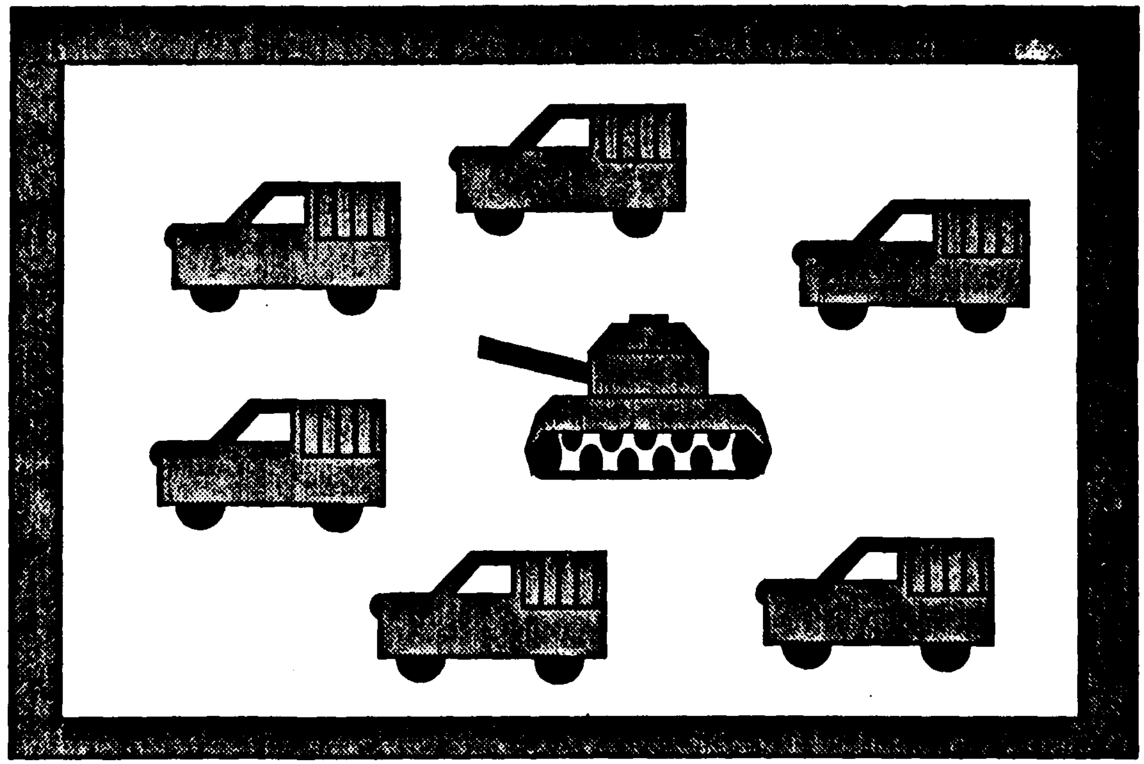
Data Set		House	People	Average	Set Average	Global Average
Learning Set	Landscape	21.2%	4.3%	12.8%	10.95%	13.68%
	Portrait	18.2%	0	9.1%		
Test Set	Landscape	20.3%	8.3%	14.2%	16.4%	
	Portrait	7.8%	29.2%	18.5%		

Consider

A given object produces a signature pattern in the optical transform that is recognizable with accuracy ε. How does the presence of other, potentially recognizable, objects in the image affect the recognition accuracy?



Recognized with accuracy ε

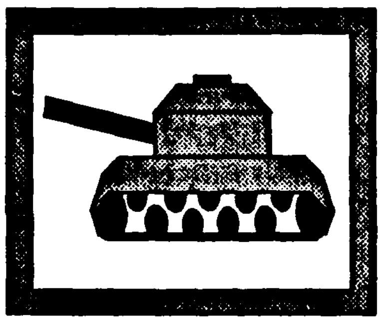


ε ?

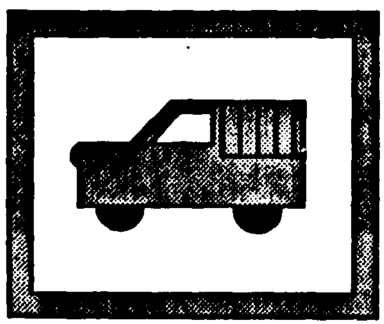
Consider

- Object A can be recognized with an accuracy of ε_a using feature F_a
- Object B can be recognized with an accuracy of ε_b using feature F_b

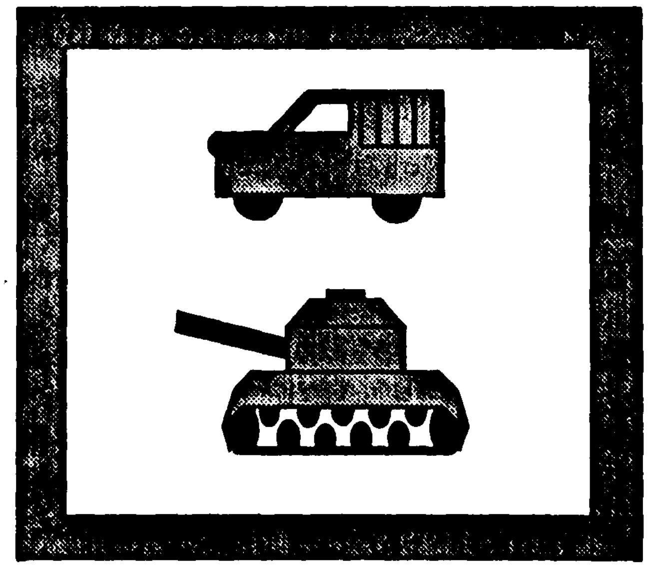
With what accuracy can both objects A and B in the same image be recognized?



Recognized with accuracy ε_a



Recognized with accuracy ε_b



ε ?

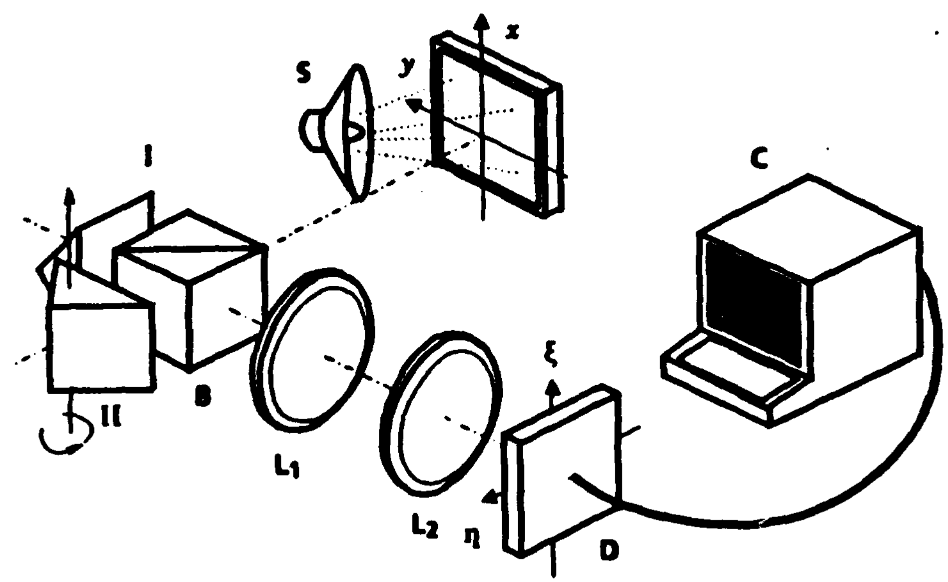
Incoherent Diffraction Pattern Sampling

Why?

- Coherent illumination requirements limit the useful applications of DPS to objects that are very smooth (on a microscopic scale) or to objects with strong specular reflections. Incoherent optical transform technology removes these limitations and allows DPS to be used in virtually unlimited applications.
- Incoherent illumination is a lot cheaper!

How?

- Incoherent-to-Coherent conversion (LCLV, PROM, etc.)
- Real-time holography
- Incoherent optical transforms *



Optoelectronic hybrid for cosinusoidal transforms of rough objects illuminated by white light

* Shen-ge Wang, *Optical Transforms in White Light*, Ph.D. Thesis, University of Rochester, 1986.

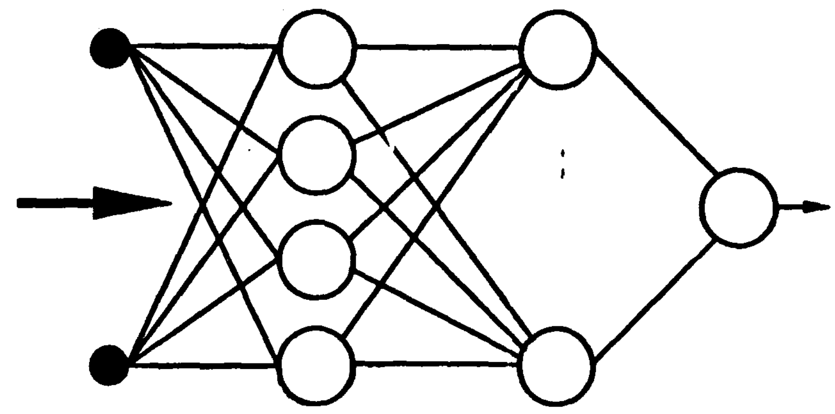
Neural Networks and Diffraction Pattern Sampling

Neural networks are:

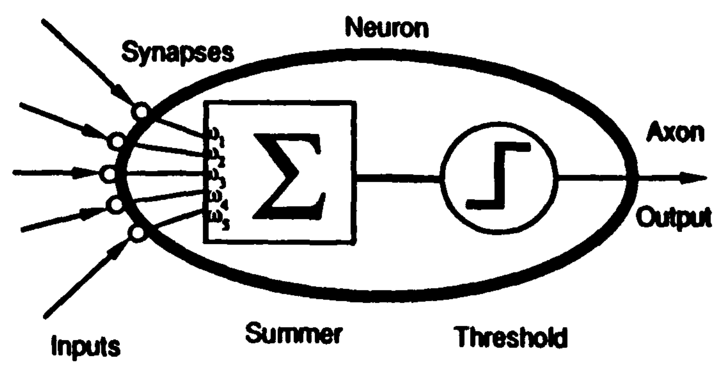
- very fast (once trained)
- can be reprogrammed for different functions
- are not limited to simple linear or piecewise-linear descrimninants

Why couple neural networks to diffraction pattern sampling?

- increase recognition speed significantly
- since RWD reduces data to 64 pixels, current neural network hardware can be used to construct a network capable of complicated descrimination



3–Layer Perceptron Neural Network



Neuron Model

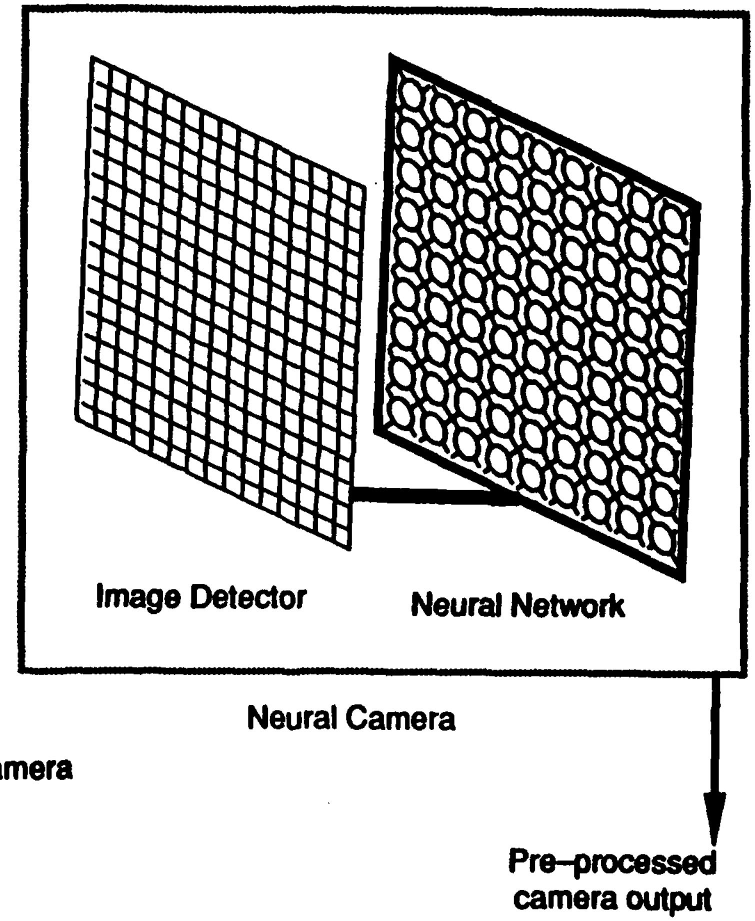
The Neural Camera

What is a neural camera?

- low–to–medium resolution image detector (ccd, vidicon, etc.)
- rectangular layout of detector elements (256x256)
- Digitized detector outputs feed into a fully interconnected neural network.

Why build a neural camera? – Configurable pre–processing within the camera

- generate a variety of transforms within the camera by adjusting the operation of the network
- perform pattern recognition, segmentation, etc. within the camera as a preprocessing function.



CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
IMAGE RETRIEVAL

Image Recovery

Rob Rolleston

The Institute of Optics

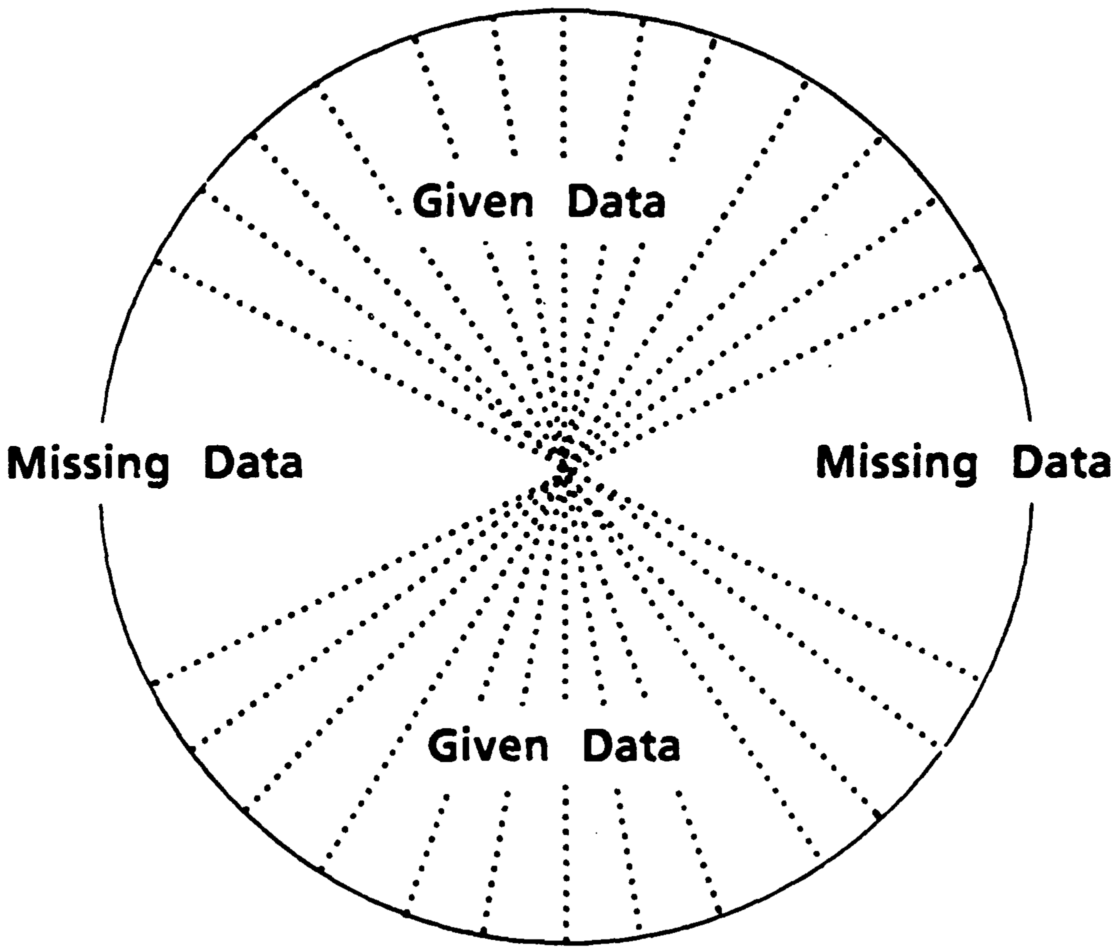
University of Rochester

Image Recovery

Given only partial information about an image and the transform, Is it possible to recover (or reconstruct) the unknown image ?

Computer Aided Tomography:

Given the Fourier spectrum only in a wedge shaped region, it is possible to fill in the missing portion of the spectrum and thus recover the unknown image.



History

1892 A. A. Michelson and Lord Raliegh

- visibility fringes

1965 Walther; Wolf

- analytic properties of functions

1974 Napier and Bates

- 2-D Polynomials

1971 Gerchberg and Saxton

- iterate between two planes

1982 Youla and Webb

- convex projections

Fourier Transform

$$G(f_x, f_y) = \iint g(x, y) \exp\{-i2\pi(xf_x + yf_y)\}\, dx\, dy$$

$$g(x, y) = \iint G(f_x, f_y) \exp\{+i2\pi(xf_x + yf_y)\}\, df_x\, df_y$$

Polar Form

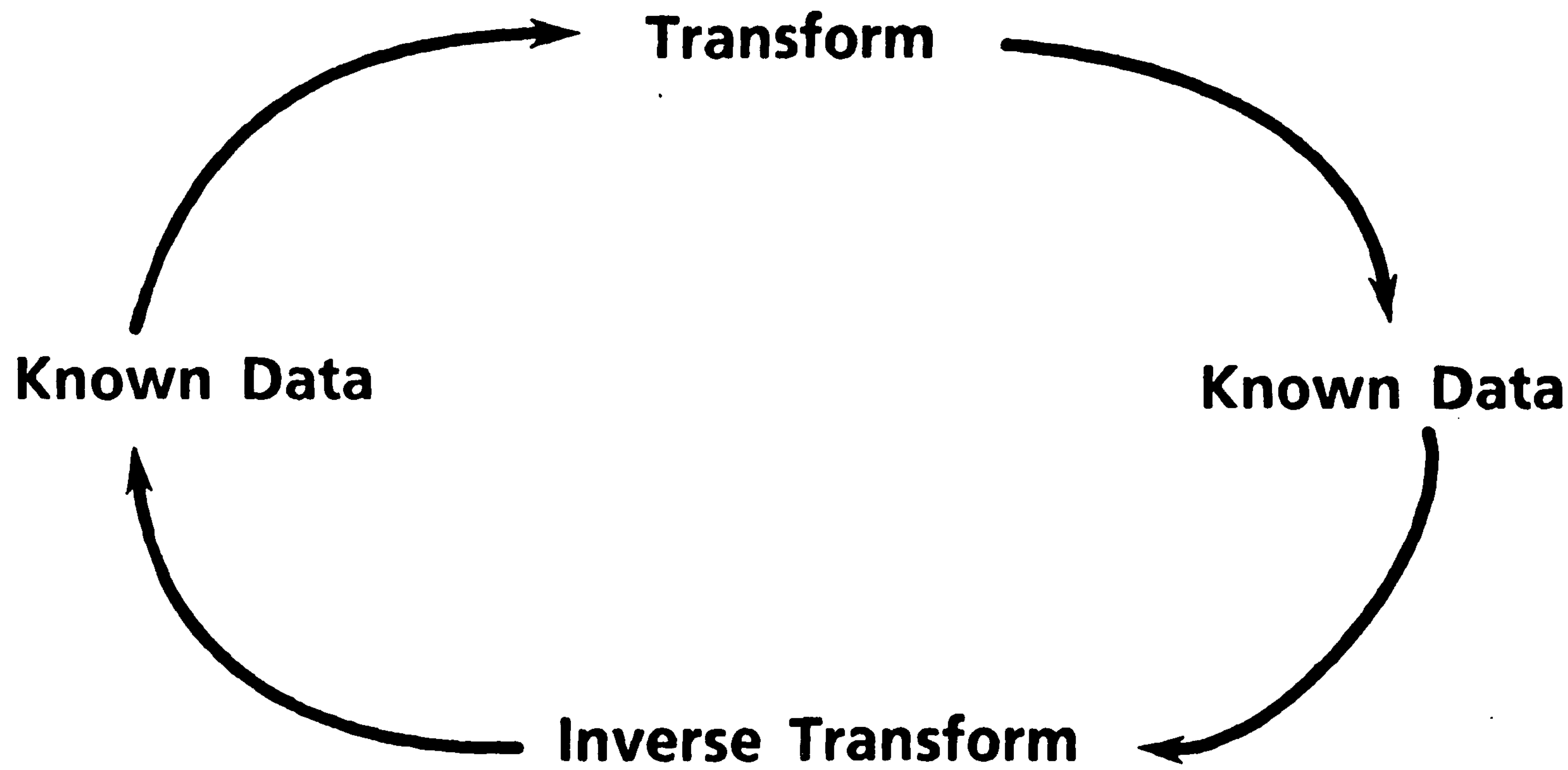
Magnitude: $|G(f_x, f_y)| = [G(f_x, f_y)G^*(f_x, f_y)]^{\frac{1}{2}}$

Phase:

$$\cos[\Phi(f_x, f_y)] = \frac{RE[G(f_x, f_y)]}{|G(f_x, f_y)|}$$

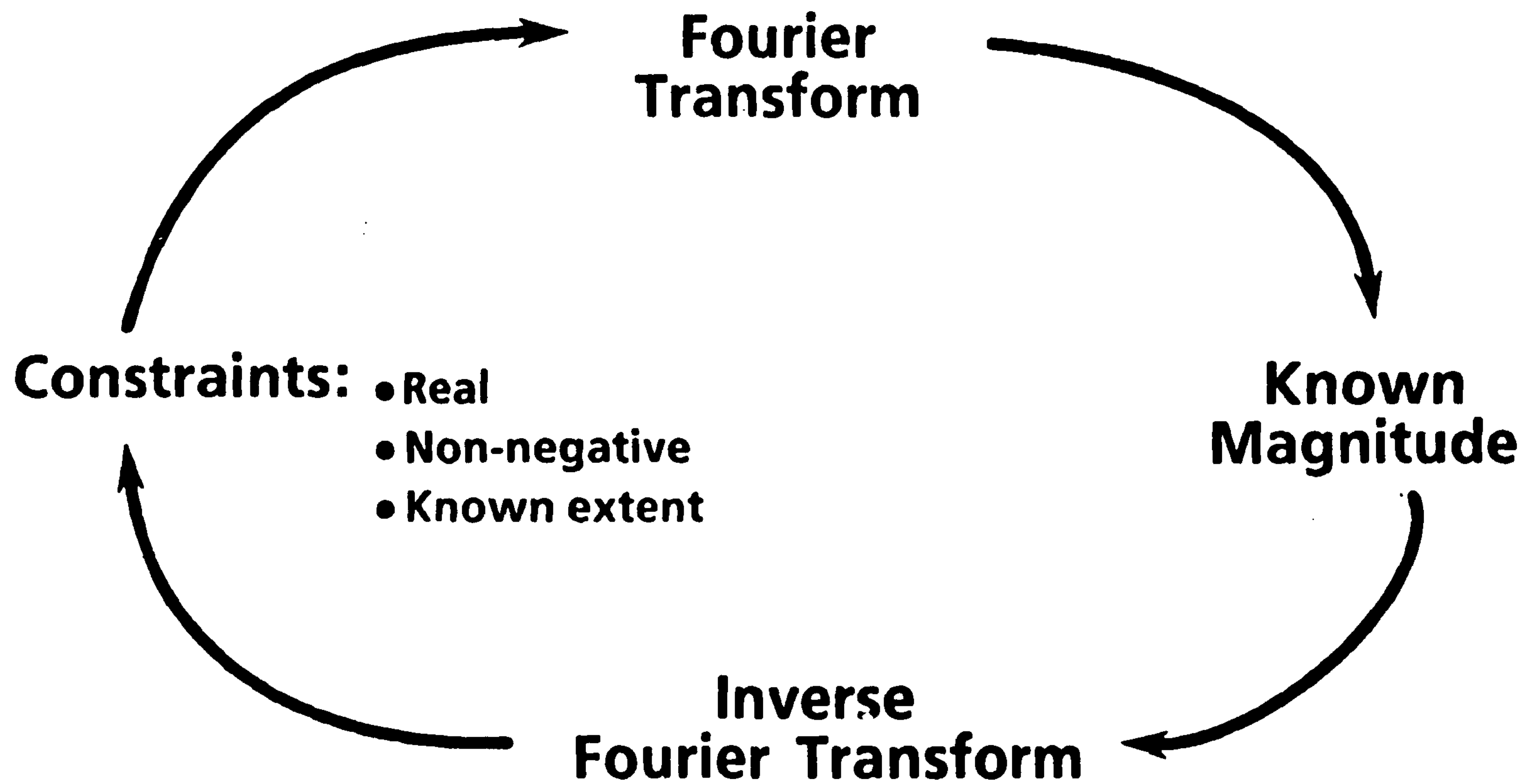
$$\sin[\Phi(f_x, f_y)] = \frac{IM[G(f_x, f_y)]}{|G(f_x, f_y)|}$$

Gerchberg-Saxton Algorithm



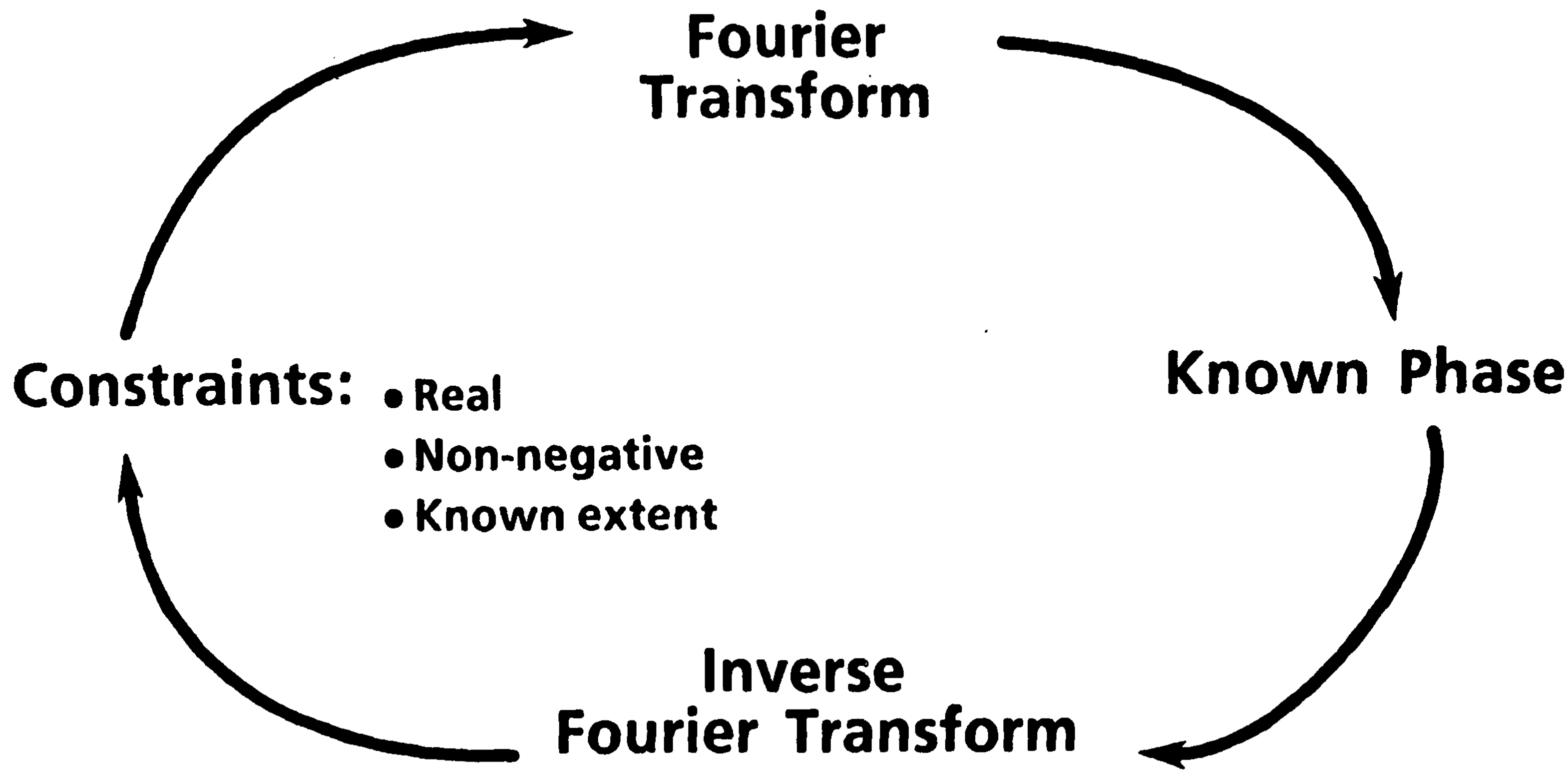
Phase Retreival

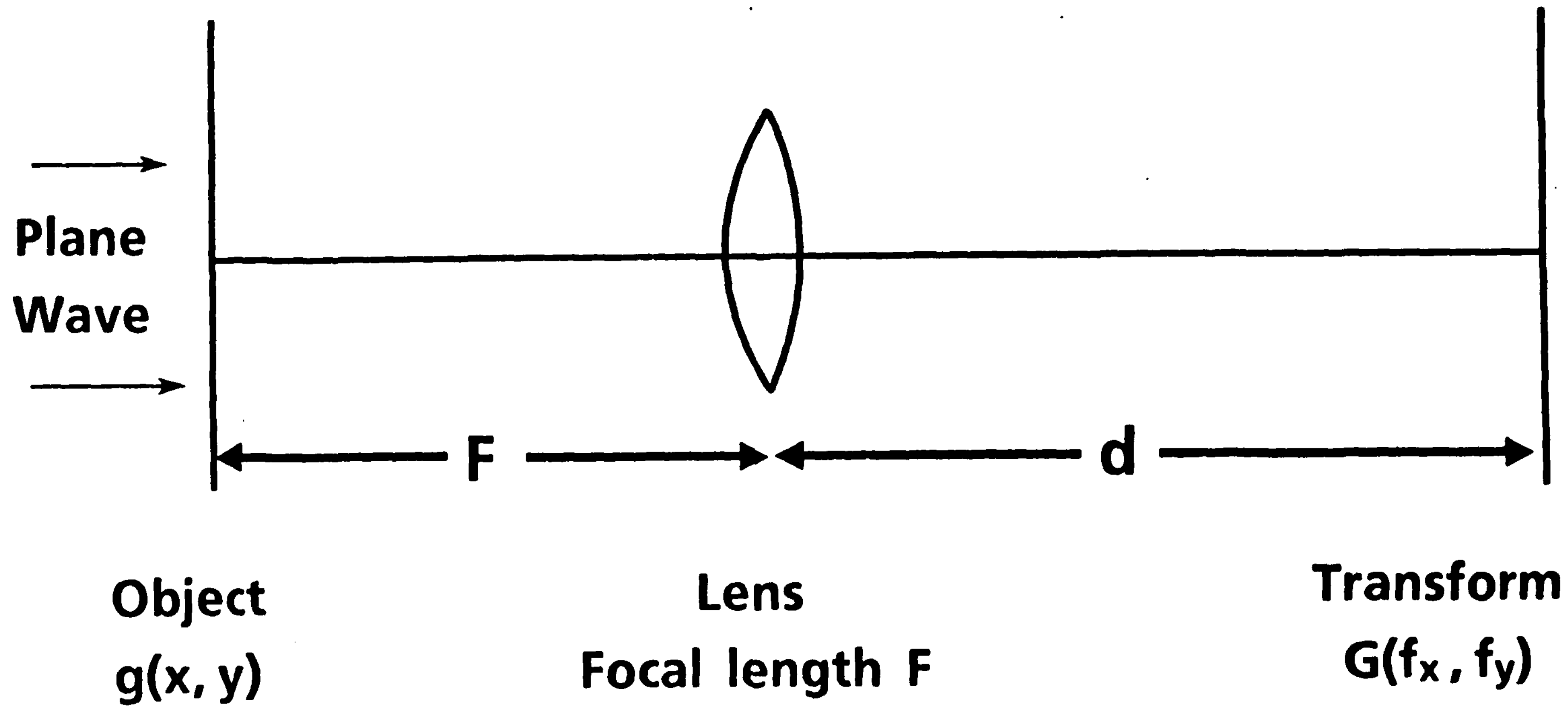
(Fienup, 1978)



Magnitude Retreival

(Oppenheim, Lim, Hayes, 1981)





$d = F$: Fourier Transform

$d \neq F$: Fresnel Zone Transform

FRESNEL-ZONE TRANSFORM PAIR

$$G(f_x, f_y) = \iint g(x, y)\, K(x,y; f_x,f_y)\, dx\, dy$$

$$g(x, y) = \iint G(f_x, f_y)\, K^*(x,y; f_x,f_y)\, df_x df_y$$

Transform Kernel

$$K(x,y;f_x,f_y) = \exp\{-i\pi\alpha_1 (x^2 + y^2) - i\,2\pi(f_x x + f_y y)\}$$

Offset parameter

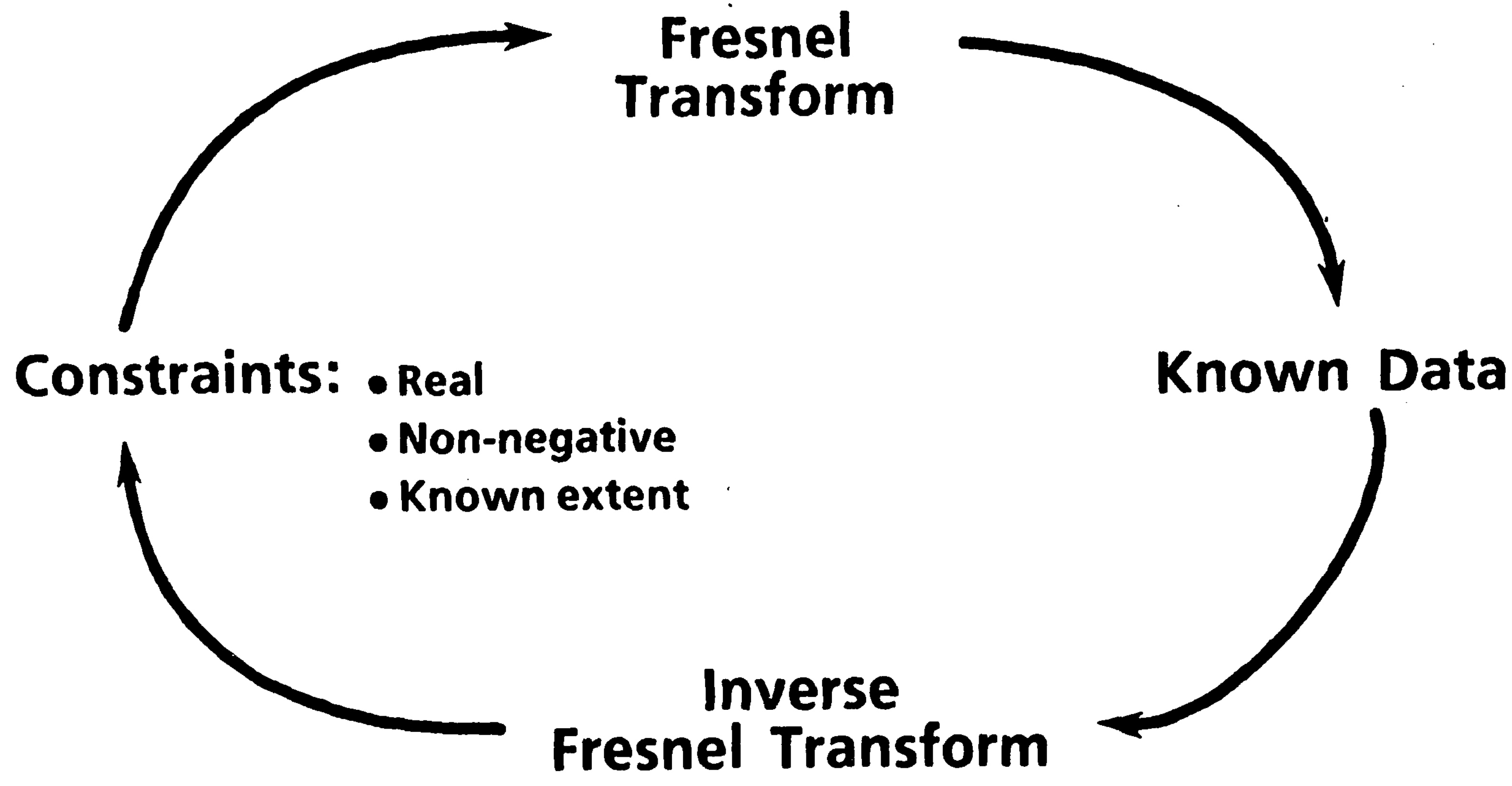
$$\alpha_1 = (1 - d_1 / F) / (\lambda F)$$

Number of Fresnel Zones

$$Z_F = [\,\alpha_1 (x_{max})^2\,] / 2$$

Image Retrieval

(Rolleston and George, 1986)



MAGNITUDE-ONLY RECONSTRUCTION

Given Magnitude of Fresnel-zone Transform

$$|G(f_x, f_y)|$$

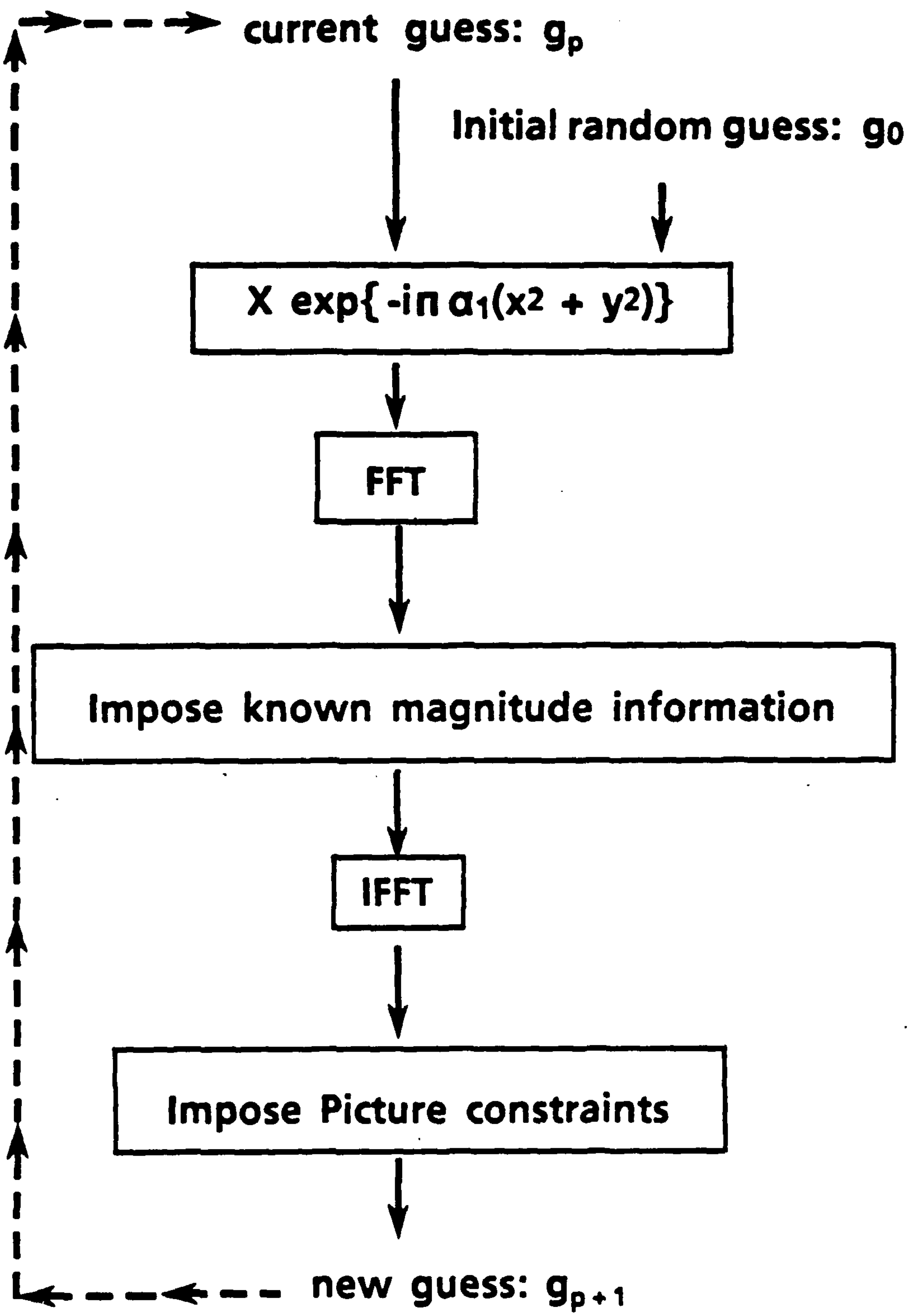
and constraints on $g(x, y)$

$g(x, y)$ is real

$g(x, y)$ is non-negative

$g(x, y)$ has a known size

Find: $\exp\{i\Phi(f_x, f_y)\}$ and $g(x, y)$

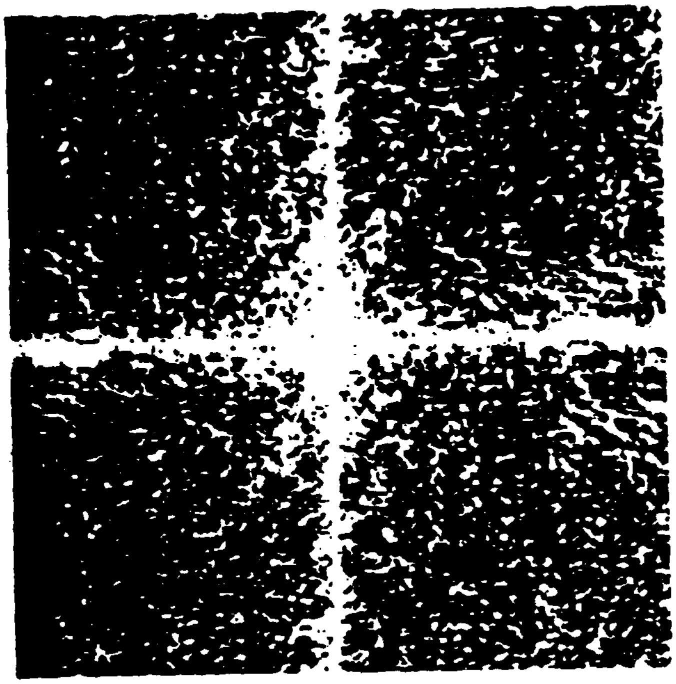


Iterative Technique of Image
Reconstruction from Magnitude Information

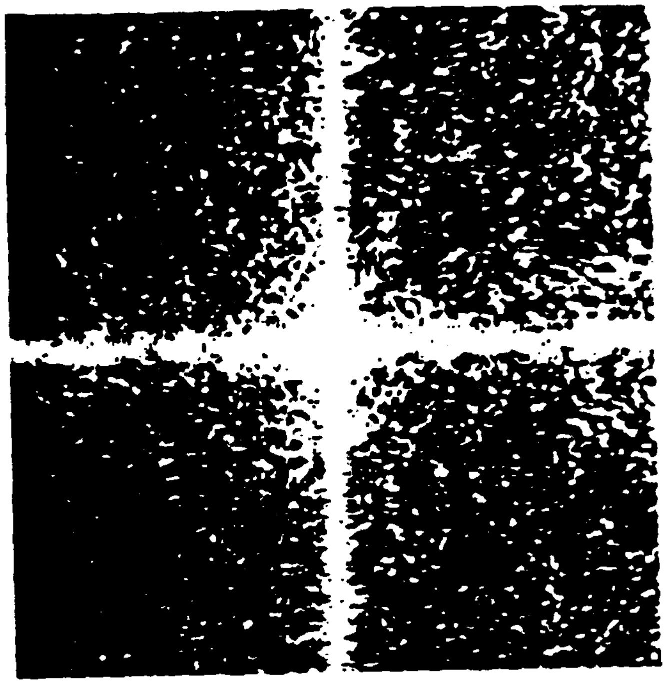
Original Image

256 x 256 Pixels

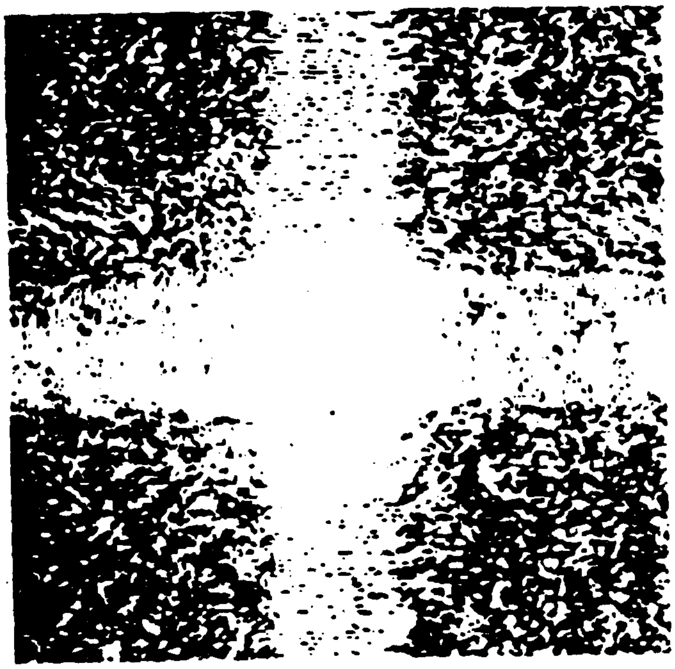
256 Gray Levels



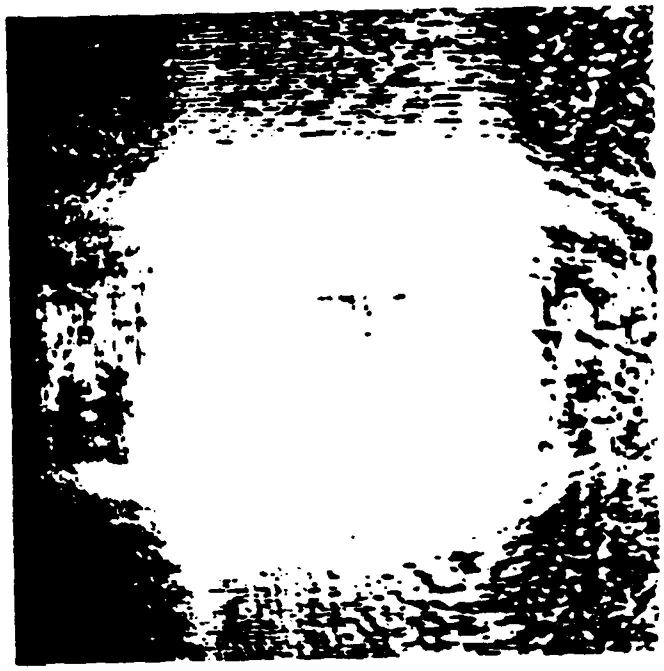
(a) $Z_F = 0.0$



(b) $Z_F = 0.5$

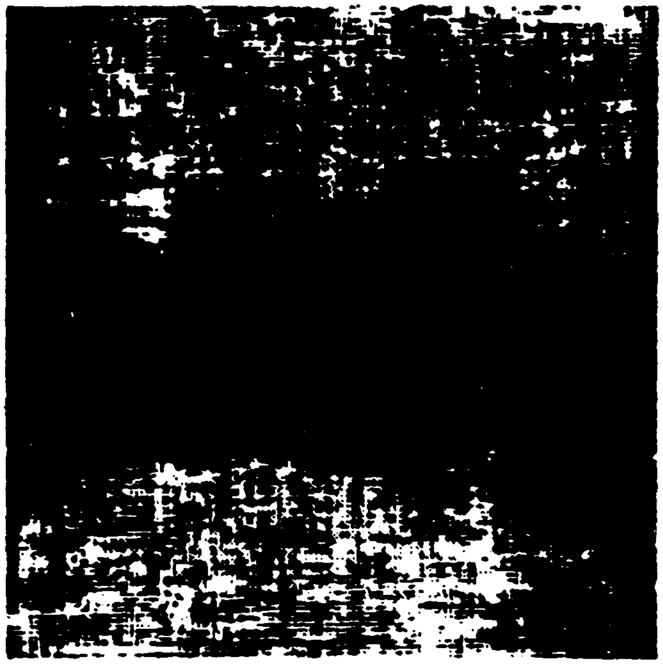


(c) $Z_F = 3.0$

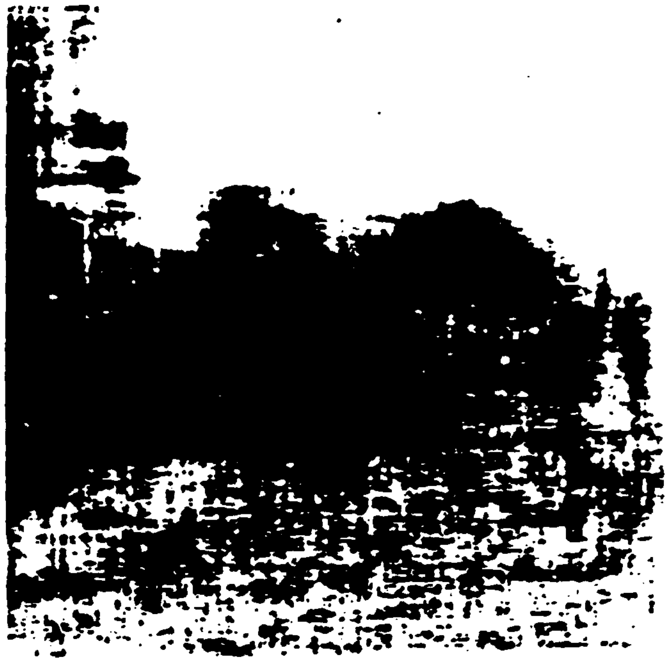


(d) $Z_F = 8.0$

Given Magnitude Data



(a) $Z_F = 0.0$



(b) $Z_F = 0.5$

(c) $Z_F = 3.0$

(d) $Z_F = 8.0$

Magnitude-only Reconstructions

PHASE-ONLY RECONSTRUCTION

Given Phase of Fresnel-zone Transform

$$\exp\{\, i\Phi(f_x, f_y)\}$$

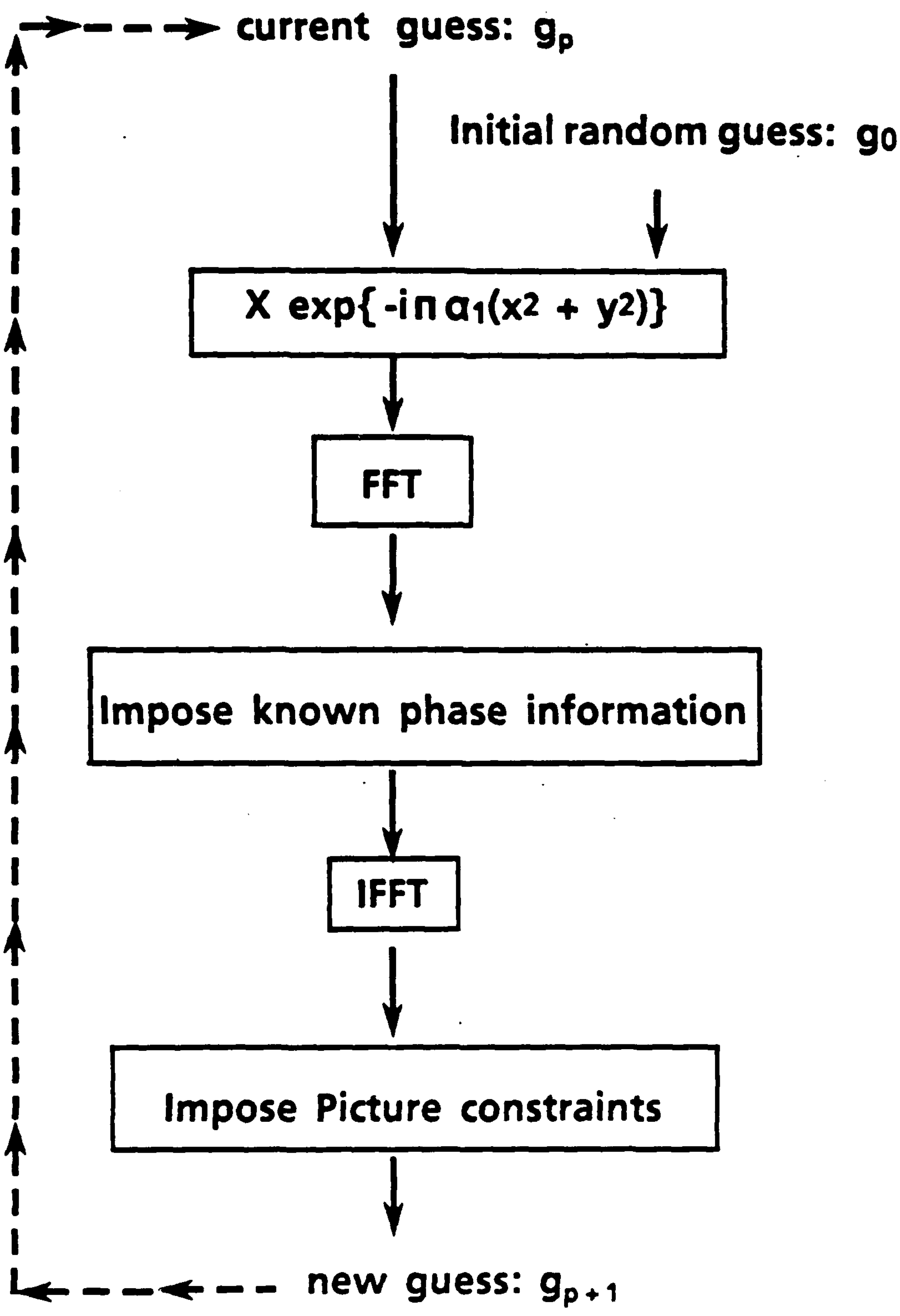
and constraints on $g(x, y)$

$g(x, y)$ is real

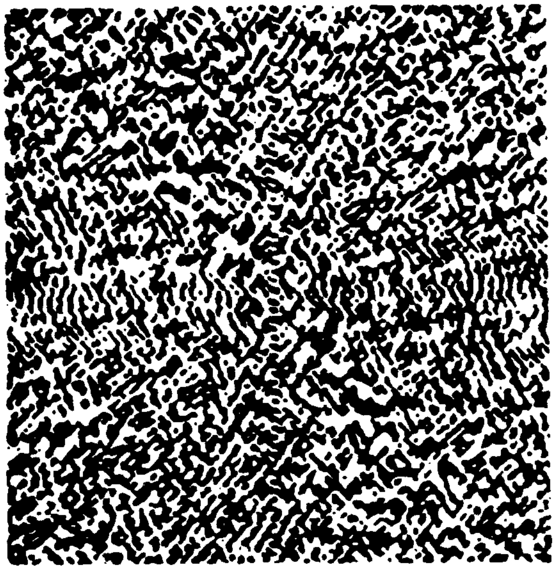
$g(x, y)$ is non-negative

$g(x, y)$ has a known size

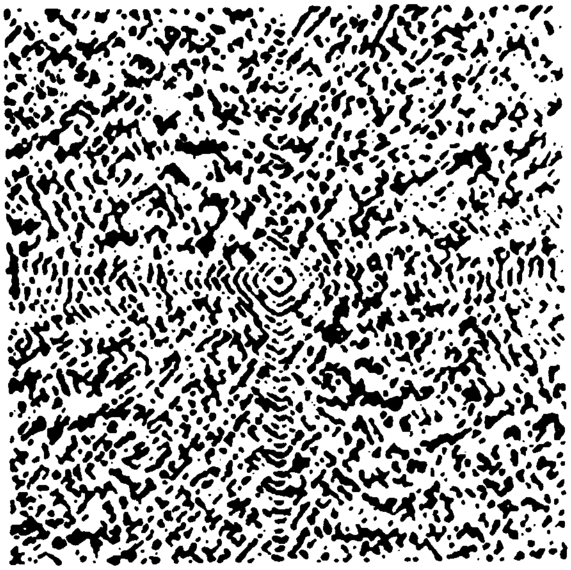
Find: $|G(f_x, f_y)|$ and $g(x, y)$



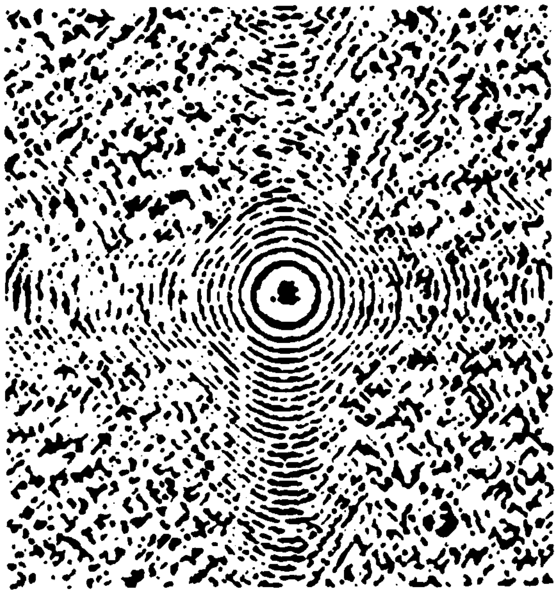
Iterative Technique of Image
Reconstruction from Phase Information



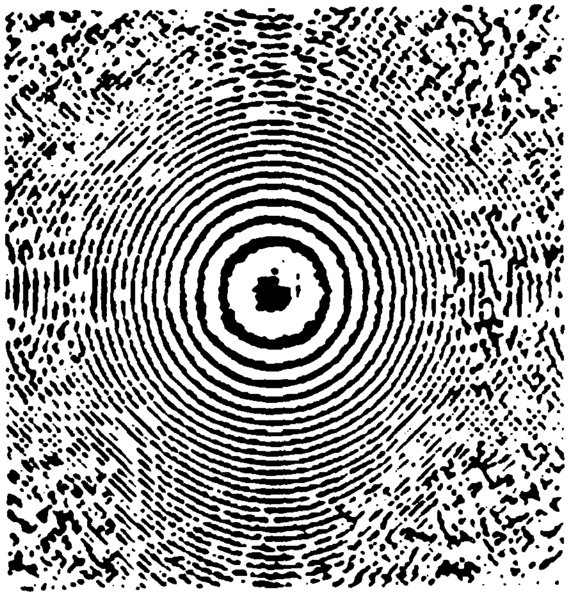
(a) $Z_F = 0.0$



(b) $Z_F = 0.5$



(c) $Z_F = 3.0$



(d) $Z_F = 8.0$

Given Phase Data

(a) $Z_F = 0.0$

(b) $Z_F = 0.5$

(c) $Z_F = 3.0$

(d) $Z_F = 8.0$

Phase-only Reconstructions

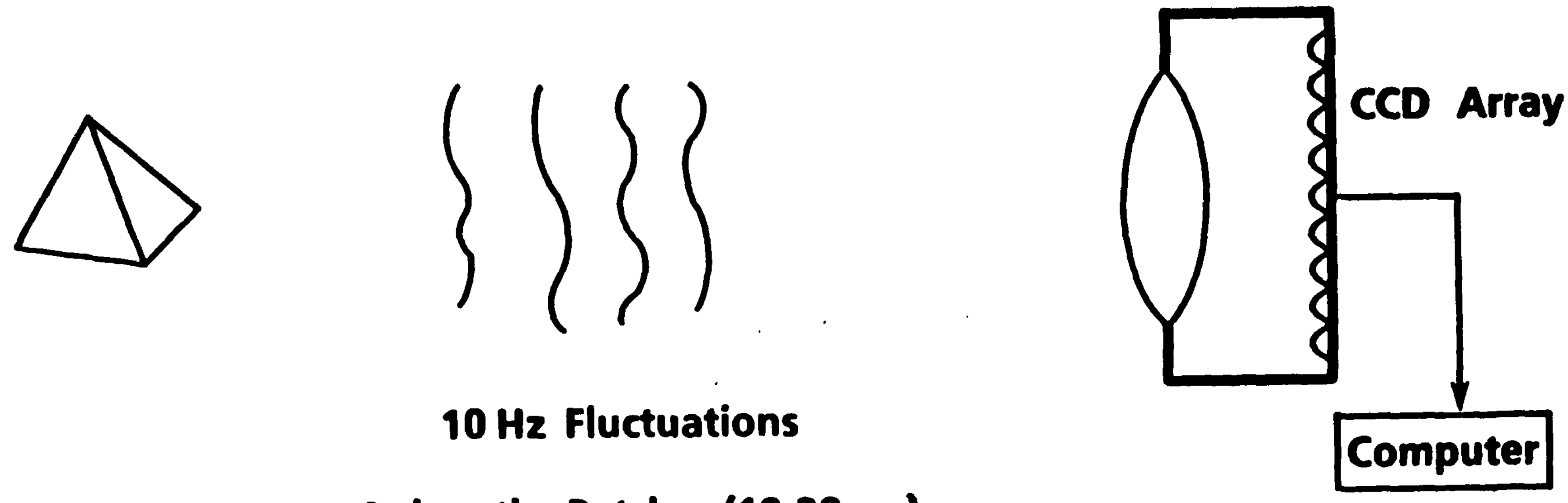
Conclusions:

- Image recovery from partial Fresnel-zone information has been demonstrated.

- Phase-only reconstructions have a slight degradation when moving out of the Fourier plane and into the Fresnel region.

- Magnitude-only reconstructions are greatly improved when moving out of the Fourier plane and into the Fresnel region.

Problem: Imaging Through Turbulence

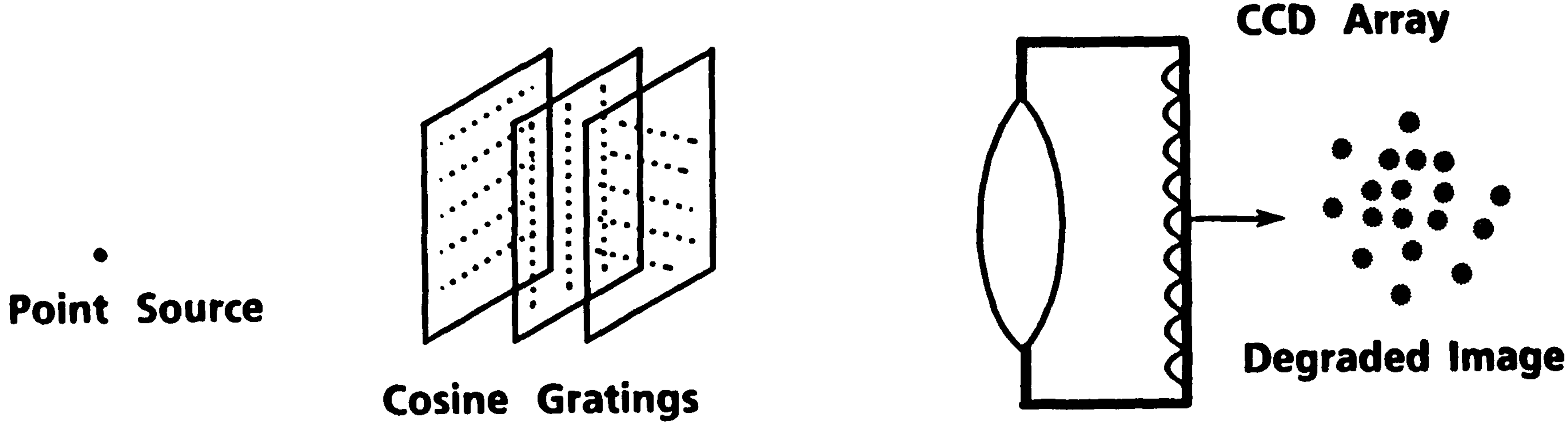


10 Hz Fluctuations

Aplanatic Patches (10-20 cm)

Improve Image Quality: $\left\{ \begin{array}{l} \text{Phase Conjugation} \\ \text{Image Recovery} \\ \text{Adaptive Optics} \end{array} \right.$

Degradation Model (short exposure)



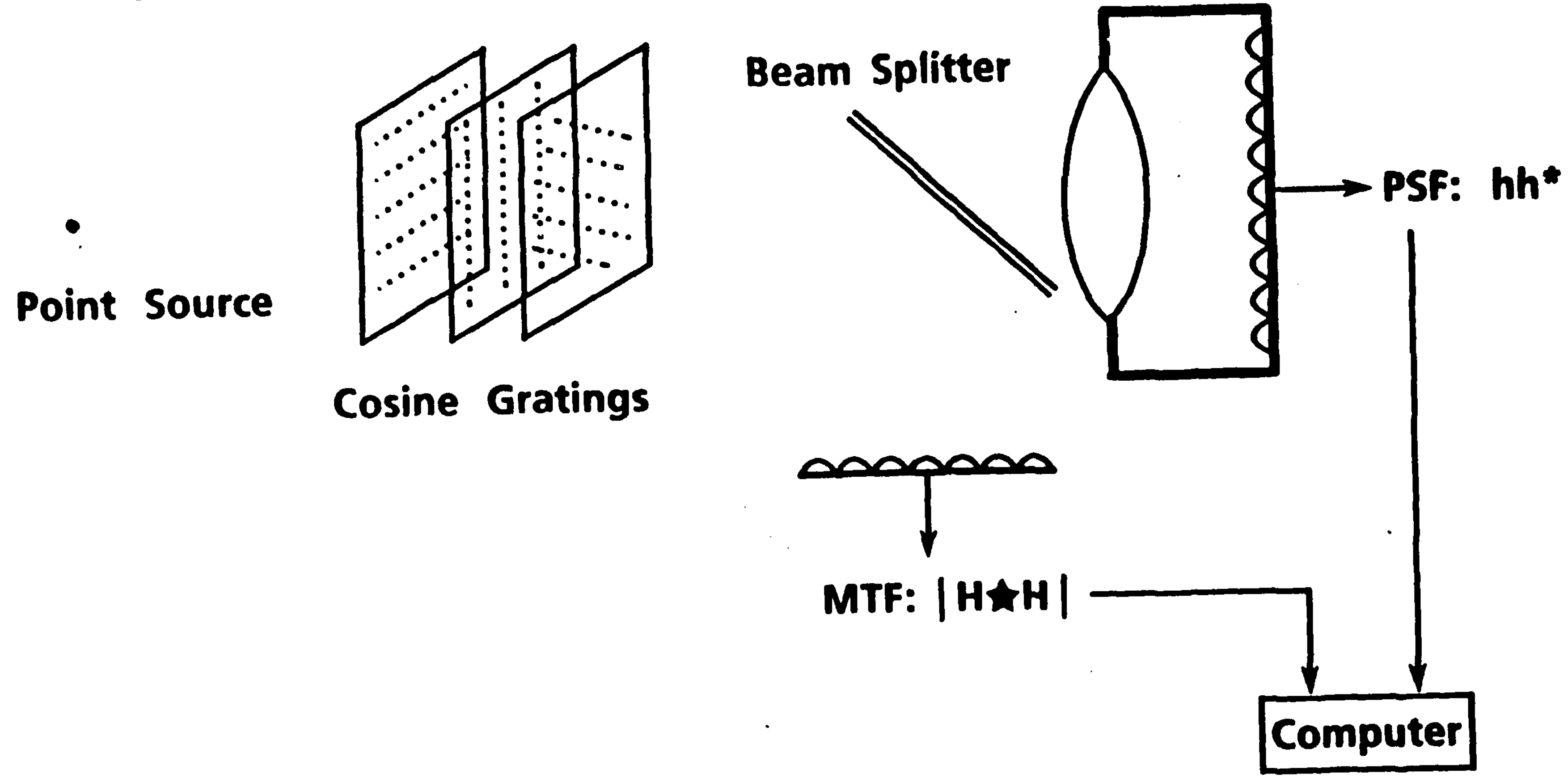
<u>Point Spread Function</u>

$$p(x, y) = \sum_{i=1}^{N} b(x - x_i, y - y_i)$$ Sum of shifted blur functions

<u>Inverse Filter Function</u>

$$P(f_x, f_y) = B(f_x, f_y) \sum_{i=1}^{N} \exp(i\pi[x_i f_x + y_i f_y])$$

Image Recovery: Current Research



Use Image Recovery techniques to recover amplitude impulse response and optical transfer function.

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CENTER FOR NIGHT VISION AND ELECTRO-OPTICS

CECOM Tests Automatic Target Recognizer

The Army reports a significant advance in its development of a new generation of night vision equipment with the completion of tests on an automatic target recognizer.

Test director John Farr of the Army Communications-Electronics Command (CECOM) Center for Night Vision and Electro-Optics, Fort Belvoir, VA, said the successful tests produced 14 sets of videotapes of collected imagery. "The data will be used in the development of night vision equipment designed to reduce the pilot's workload and the time it takes to find a target," Farr said.

Tests were conducted with a sensor package mounted on the nose of a helicopter. A video screen inside the aircraft displayed target objects and the heat they emanated. The imagery was recorded on high-resolution videotape.

The objective was to collect continuous 875-line imagery of different types of military targets. Four target types were used — tank, armored personnel carrier, truck and high mobility, multi-wheeled vehicle. More than 70 low-altitude runs were made over two weeks at CECOM's Central Oregon Test and Evaluation Facility.

Using the collected data, engineers will "teach" the automatic target recognizer to detect and classify targets from sensor output. As technology develops, the target recognizer will be able to discriminate among friendly and hostile vehicles and aircraft, prioritize targets and direct fire toward the highest threat target.

Eventually the automatic target recognizer will be mounted on remotely piloted vehicles. With the ability to differentiate between live and spurious enemy warheads, the automatic target recognizer will help drivers of tanks and other land vehicles navigate and lock in on targets.

The imagery collection effort involved the use of a unique night vision system employing a Type 1 utility helicopter with a target acquisition designator system.

An Army UH-1 helicopter was fitted with a nose-mounted support for two high-resolution imaging sensors. The tapes have two audio tracks, one carrying verbal instructions, the other continuous range information from the primary target to the target areas.

The Oregon National Guard provided eight target vehicles and drivers for the tests. Two M60A3 tanks, two M113 armored personnel carriers, two M35 2½-ton trucks and two of the Army's new high mobility, multi-wheeled vehicles were split between the two target areas a little over six miles apart.

1A

5. LIST OF ATTENDEES

OPTOELECTRONIC WORKSHOP

AUTOMATIC PATTERN RECOGNITION

April 7, 1988

NAME	ORGANIZATION	PHONE
Nick Barr	NVEOC	703-664-4931
Rudolf Buser	NVEOC	703-664-3067
Todd Carr	NVEOC	703-664-5286
Tom Colandene	NVEOC	703-664-5310
John Curry	NVEOC, GSD	703-664-1424
Friedrich de Groot	NVEOC, LET	703-664-2730
L. N. Durvasula	NVEOC	703-664-1064
Mark Gahler	NVEOC, ASD	703-664-6665
Lynn Garn	NVEOC	703-664-6066
Reinhold Gerharz	NVEOC, ACD	703-664-6267
John Horger	NVEOC	703-664-3043
David R. Kaplan	NVEOC	703-664-3063
C. Math	NVEOC	703-664-1968
Mark Norton	NVEOC	703-664-1968
Richard Peters	NVEOC, ACD	703-664-6066
Helmut Pistor	NVEOC, LET	703-664-2730
Juergen Pohlmann	NVEOC	703-664-1432
Mark Savan	NVEOC	703-664-4931
David Singer	NVEOC, ACD	703-664-6066
Jay Sonstroem	NVEOC	703-664-5310
Khanh Tran	NVEOC	703-664-1900
Nicholas George	UR, Optics	716-275-2417
Robert Rolleston	UR, Optics	716-275-6195
Tom Stone	UR, Optics	716-275-7834
Dennis Venable	UR, Optics	716-275-5805